UNHOLTZ-DICKIE CORPORATION

MP MASTER
MA34529

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Vibration Testing System

26208

Operating and Maintenance Manual

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WARRANTY

All products are warranted to be free of defects in material and workmanship for a period of one year* from date of shipment. If the product is not installed, maintained and used in a normal manner in accordance with instructions and manuals, this warranty will not apply. Commercial parts purchased and installed in the product will only carry the original manufacturer's warranty.

This warranty is limited to repairing or replacing parts which have been returned and in our opinion are defective. Service required to correct defects in material or workmanship will be supplied without charges. The Buyer will pay all transportation and taxes incurred. This warranty does not cover any costs incurred by the Buyer as a result of purchase of UNHOLTZ-DICKIE CORP equipment or any charges for the Buyer's labor for replacement, adjustment or repair unless authorized in advance in writing. We are not liable for consequential damages.

This warranty will not apply to any products which, in the opinion of UNHOLTZ-DICKIE CORP, have been subject to accident, misuse or neglect; altered or repaired with a substitute which might impair the product; or used outside of rated conditions. UNHOLTZ-DICKIE CORP reserves the right to make improvements in its products including changes and additions without incurring obligations to incorporate such improvements in previous units.

This warranty is expressly in lieu of any and all other warranties or commitments, expressed or implied and any other obligations to the Buyer associated with the use of UNHOLTZ-DICKIE CORP products.

**Shaker moving elements and suspension parts are warranted for a period of TWO YEARS from date of shipment.*

Rev. 9/1967

A. SYSTEM SPECIFICATIONS

Generated Force, continuous rating	1200 lbs. peak
Armature Assembly effective weight	20 lbs. Nom.
Maximum Free table acceleration	60 g
Shaker Stroke - Snubber to Snubber	1 1/4 inches
Shaker Table suspension stiffness	600 lbs./in. Nom.
System Performance	See Curve No. Q 290
Free table axial resonant frequency	3000 cps Nom.

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B. SYSTEM DATA

Vibration Testing System: No. 262-8

Shaker: Model No. 160-8

Serial No. 118

Control Console: Model No. MA262-8 S.N. 137

Automatic Shaker Control: Model No. BK1025

Serial No. 199917

Oscillator: Model No. —

Serial No. —

Dial-A-Gain: Model No. 601R-A S.N. 230

Effective capacity at input connector: 6 pf
(see page E3)

Power Amplifier: Model No. A102

Serial No. 194

Input Power:

Volts	Phase	System KVA
115	1	1
208	3	13

Shaker:

Field Coil:

Cooling: AIR

Water — gpm, ____ to ____ psi, ____ °F. Max.
Maximum current after warm up: 4 amp d-c
Resistance - room temperature: 1.5 ohm.

Degaussing Coil (Optional Accessory)
Optimum current setting — amp d.c.

Shaker (Continued):

Driver Coil:

Cooling: Air

Maximum current: 40 amp. a-c

Resistance - room temperature: 0.2 ohm.

Table Accelerometer:

Mfr: UNHOLTZ-DICKIE

Model: 20D21 Serial No. 133

Outline dimensions and table bolt pattern:

Refer to Bulletin attached

Amplifier:

Cooling:

____ Air

Water, _____gpm_____to_____psi,_____°F. Max.

UNHOLTZ-DICKIE CORPORATION

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ACCELEROMETER CALIBRATION

MODEL 20D21 SERIAL NO. 133

DATE OF CALIBRATION 12-28-67 BY JI

LOADED CIRCUIT VOLTAGE SENSITIVITY: S_L = 11.943 $\frac{\text{mv-rms}}{\text{g-pk}}$ at 100 Hz

ACCELEROMETER CAPACITANCE: C_A = 1357 pf at 100 Hz, 1313 pf at 1000 Hz

LOAD CAPACITANCE: C_L = 206 pf

OPEN CIRCUIT VOLTAGE SENSITIVITY: $S_{oc} = S_L \left(\frac{C_A + C_L}{C_A} \right)$

S_{oc} = 13.75 $\frac{\text{mv-rms}}{\text{g-pk}}$ at 100 Hz

FREQ. Hz	20	40	100	200	400	1000	2000	4000
% DEV. S_{oc}	+0.75	+0.35	0.0	-0.5	-0.7	-0.9	-0.3	+1.4

OPEN CIRCUIT CHARGE SENSITIVITY: $Q = \frac{S_{oc} C_A}{.707}$

Q = 26.39 $\frac{\text{pcmb-pk}}{\text{g-pk}}$ at 100 Hz, 25.41 $\frac{\text{pcmb-pk}}{\text{g-pk}}$ at 1000 Hz

SIDE SENSITIVITY, MAXIMUM % DEVIATION AT APPROX. 200 Hz 3.4 %

THIS CERTIFIES THAT THE ABOVE CALIBRATION DATA IS TRACEABLE TO THE NBS LABORATORY NUMBER 213.23/190142, AND THAT THE ACCELEROMETER MEETS THE PUBLISHED SPECIFICATIONS.

D. McCluskey

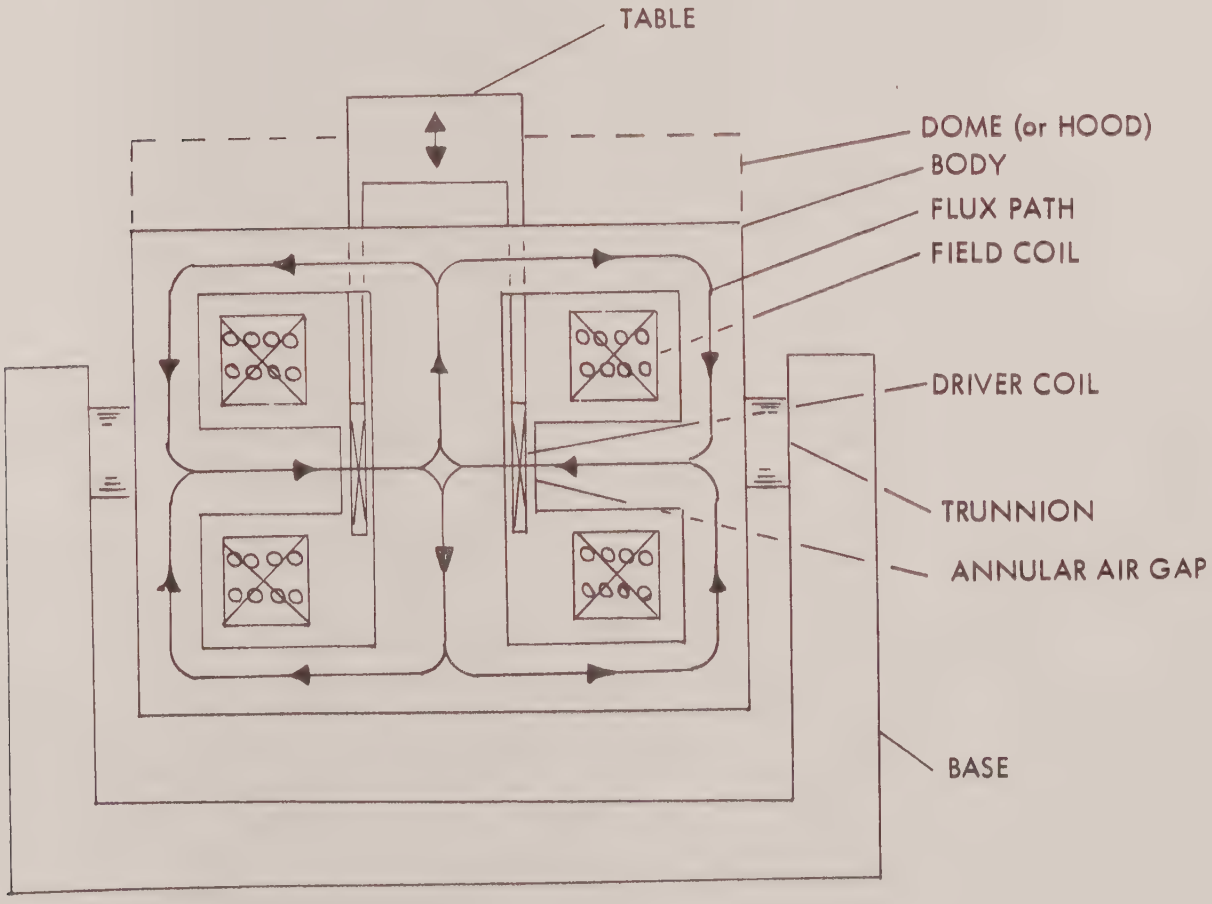
DATED: 2-13-68

C. DESCRIPTION OF SYSTEM

The Vibration System usually consists of three separate parts, the Shaker, the Control Console and the Electronic Power Amplifier. In some of the smaller systems the Power Amplifier is located within the Control Console leaving two separate parts.

1. Shaker

The Shaker is the heart of the system. It provides the vibrating table to which the items to be tested are attached. The principal parts of the Shaker are shown in the illustration.



SHAKER SCHEMATIC DIAGRAM

The air cooled field coils energize the Shaker body with flux paths as shown creating a high magnetic flux density in the annular air gap. The field coils are connected to a d-c power source. The armature assembly, consisting of the table and driver coil, is suspended from the Shaker body by the Unholtz-Dickie table suspension. When an alternating current is passed through the driver coil, an electrodynamic force is generated in the driver coil wires causing the table to move as indicated by the double ended arrow drawn on the table. The frequency of the alternating current determines the frequency of vibration in the table. The table motion depends on the magnitude of the generated force, the mass of the table and load attached to the table, the stiffness of the table suspension and other factors. The motion of the table is limited by the maximum stroke of the Shaker, the available voltage from the electronic Power Amplifier in the low frequencies and by the rated force or maximum acceleration in the higher frequencies.

The Shaker is trunnion mounted allowing it to be oriented for vertical or horizontal vibration or any position between these limits. In larger shaker models such as the Models 206, 56 and 500, a resilient mounting is incorporated in the trunnion mount to isolate the vibration of the Shaker from the base and mounting floor.

The Shaker includes electrical switches which trip just prior to contacting the table displacement limiting snubbers. A temperature safety limit switch is also in contact with the field which protects the shaker from overheating or other causes. If this switch trips, the system is automatically shut down and requires manual restarting. (Note: this switch is omitted on the Model 105 Shaker.)

An accelerometer is attached to the internal end of the table central flanged load attaching insert. This accelerometer, in conjunction with the Dial-A-Gain signal conditioning preamplifier and the automatic shaker control vibration meter, indicates shaker table vibratory displacement, velocity or acceleration.

II. Electronic Power Amplifier

The Electronic Power Amplifier input is connected to the controlling oscillator signal source and the output is connected to the driver coil of the Shaker. The oscillator generates a low power, low voltage signal which is amplified by the Electronic Power Amplifier to the necessary power and voltage levels to cause the a-c currents to flow through the driver coil as required to generate rated force. The Power Amplifier is of straight forward design to provide the necessary power levels through the operating frequency range without introduction of significant distortion. The Amplifier is described in detail in the following pages.

The Electronic Power Amplifier is a complete unit and is located in the Control Console, together with all necessary control circuits and instruments.

MODEL A102 AMPLIFIER

Introduction

The Model A102 Audio Power Amplifier is specifically intended to provide a high power, low distortion source for driving the Unholtz-Dickie Models 100,200 and 500 Shaker types. Expandability is designed into the amplifier by providing for addition of a second amplifier in series which is easily done in the customer's plant.

Description

The basic A102 Amplifier is a multiple output tube design, based on a successful smaller amplifier used with Unholtz-Dickie calibration shakers. This multiple output tube type attains lower distortion than ever before possible with high power tube amplifiers, based on the "Ultra Linear" feedback connection, well known in High Fidelity Amplifier Systems. A second major advantage of this amplifier is the relatively low voltages encountered. The maximum tube voltage is 600 volts (compared to 6,000 volts on typical tube power amplifiers), greatly reducing the hazard to personnel.

A major feature of the design is the addition of [redacted] new protective circuits on the power amplifier. It is virtually impossible to overdrive the amplifier at any frequency, or under any load condition, thus insuring long tube life, and greatly increasing amplifier reliability. These protective circuits are described in detail below.

The amplifier is a modular, plug-in type, with the preamplifier and driver stages mounted in a separate $5\frac{1}{4}$" high rack mounted chassis. The output tubes and circuitry are mounted in removable trays, twenty tubes per tray. Both the preamp and the output tube trays have all quick disconnect connections, and are individually fused.

Circuit

The Model A102 Amplifier utilizes a transformer input to obtain a balanced push-pull circuit throughout. The preamplifier consists of two 12AT7 tubes for two stage amplification. The signal is then applied to the cathode follower driver stages, consisting of two 12AT7 tubes. The signal then goes from the preamplifier chassis to the output tube trays to drive the output tubes type [redacted], forty pairs. The output stages are connected in the unique ultralinear connection wherein feedback from the plates to the screens through the output transformer greatly reduces distortion. Feedback is also taken from the secondary of the output transformer to the first preamplifier stage to decrease the distortion still further.

Amplifier Protective Circuits

In addition to the usual system protective devices this amplifier incorporates new protective shutdown circuits which prevent overdriving the amplifier at any frequency. The circuits are as follows:

1. Overvoltage

   The output tubes are protected from voltage overdrive by a fast acting relay circuit which monitors the average value of the screen current, which is a sensitive indicator of overdrive. The circuit is factory set to trip at the maximum voltage level, and puts the system on standby.

2. Overcurrent

   The output tubes are protected from drawing too much current by peak clamping circuits which monitor the cathode current. Any current peaks which exceed the factory set level energize the fast acting relay circuit to put the system on standby. This peak clamping circuit will detect either high peak sine currents at higher frequencies or current spikes occurring at low frequencies due to saturation of the output transformer.

Initial Startup of Amplifier

When the amplifier and system are first received or if the system is being reinstalled or relocated, the following steps and precautions should be observed.

1. All tubes, fuses and interconnecting cables and chassis should be in place.

2. Check the incoming 3 phase line voltage, i.e., 240, 208, etc. Check that the A102 power transformer T24 voltage connections are on the proper connections.

3. Open the rear console doors and pull the door interlock switches out to close the interlock.

4. Turn down the amp. gain switch (on the preamp. panel) full CCW.

5. With the 3 phase and single phase power on to the system, push the "Preamp On" lighted pushbutton. The console fans should start, the console instruments should turn on. Observe the output tubes and note whether the filaments light up after 20 or 30 seconds. The panel meters "Cathode Current A & B" should not read at this point.

CAUTION: DO NOT APPLY HIGH VOLTAGE by pushing the "Operate" lighted pushbutton.

6. Check the bias voltages on the test jack points "Bias A" and "Bias B" on the front panel of the preamp. chassis. They should be adjusted with a screwdriver to read -76 to -78 volts D.C.

7. There will be a time delay of approximately 120 seconds before the "Standby" light lights, indicating that the filaments have had time to warm up.

8. Only after being sure that the output tube filaments are all lit, and the bias voltages are correct, after the preamp light is on, apply high voltage to the amplifier by pushing the "Operate" pushbutton. At this point, the shaker field will come on if its powerstat control is up, and the shaker blower will start up. The shaker blower rotation should be checked to agree with the rotation arrow. If incorrect, reverse two leads of the 3 phase power at the customer wall disconnect. Now the panel meters "Cathode Current A & B" should be reading approximately 0.8 amps. Readjust the bias pots to obtain this bias current.

9. At this point this system is ready to operate. Refer to Section D to operate the system.

Maintenance Notes

1. The output voltage of the Amplifier is easily monitored by means of a front panel jack located under the writing desk surface.

2. If for any reason the system appears to be malfunctioning, refer to Section O for some simple system checks.

3. If the trouble is in the A102 Amplifier, there are several steps and observations that can be made.

4. If the "Operate" light is on, and either or both of the "Cathode Currents" have dropped to a much lower level, and the Bias test voltages are normal, it probably indicates blown 4 amp. fuses on the output tube trays. If blown fuses continually occur when pushing the "Operate" light, there is possibly a bad tube. If the tubes are observed when pushing the "Operate" switch (with the fuses replaced), it is usually possible to see a blue flash in the bad tube. Pull the suspected tube from the socket and repeat the procedure. The amplifier may be operated with one or more tubes missing from the tube sockets with a corresponding reduction in peak power. A grid to screen short circuit in one tube can be located easiest by bringing the system only up to "Standby", then measuring the -76 volt bias voltage on the tube tray bus bars for both the grid (where it is normally measured) and on the screen bus bar (where it appears abnormally due to the fault). Next, remove one tube at a time. When the bad tube is removed, the -76 volts will disappear from the screen bus bar.

5.

6.

7.

4(a) In dual amplifier systems there are two A102 Preamplifier chassis. The one located in the central rack with the oscillator is the master control unit. The toggle switch on the rear of the master unit should be set to "Master" and the switch on the slave unit to "Slave." The preamps are interchangeable. The only difference between units is a phase reversal at the input transformer.

5. If the bias voltage is not present in standby position, check the 1.0 amp. power supply fuse.

6. If one or more of the protective shutdown devices is suspected of trouble, it is possible to remove the tube in the tube socket adjacent to each protective relay, located on the underside of the output tube trays. With this tube removed, the associated relay circuit will not function and cause shutdown.

7. On dual A102 systems, it is a simple matter to connect the system for single amplifier operation. Then comparisons can be made between preamp chassis, or tube trays, for example, by plugging in both units into the single A102 consecutively, to pinpoint which chassis has trouble. The system can be operated at 70% of its full rating on this single A102 connection. This enables many tests to continue while a faulty chassis or component is being replaced. See diagram on next page for reconnections for single amplifier operation.

8. When performing any extensive trouble shooting, it is a wise precaution to remove the lead on the holding coil of relay 6. This prevents applying the plate voltage to the output tubes if the front panel "Operate" button is pushed inadvertently.

FEEDBACK ADJUSTMENT:

The amplifier includes a potentiometer to adjust the feedback on one side relative to the other. This adjustment is made at the factory and should not need alteration. In case it is misadjusted, the setup procedure is as follows:

With the amplifier operating @ 500 cps, connect the X and Y axis of an oscilloscope to the grids (pin 7) of V_1 and V_3 respectively. Then adjust FBK until the signals are approximately equal and out of phase. Be sure that the X and Y axis amplifiers on the scope are set for equal gain.

Rev. 11-13-67
12-5-67
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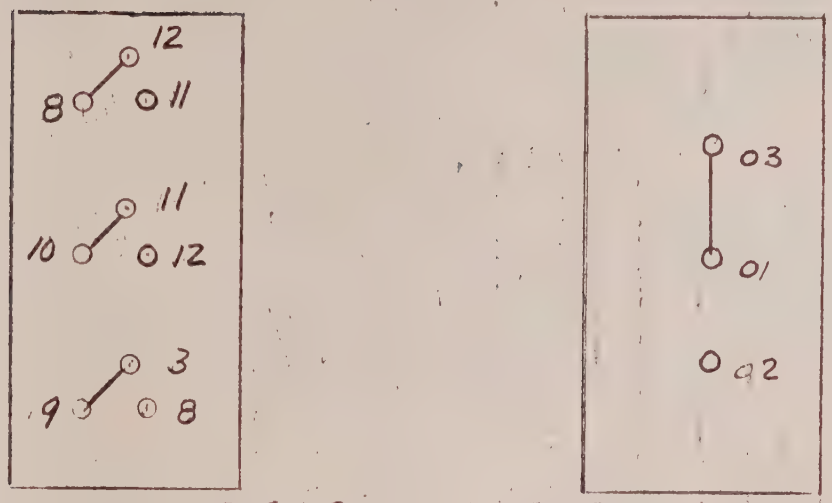
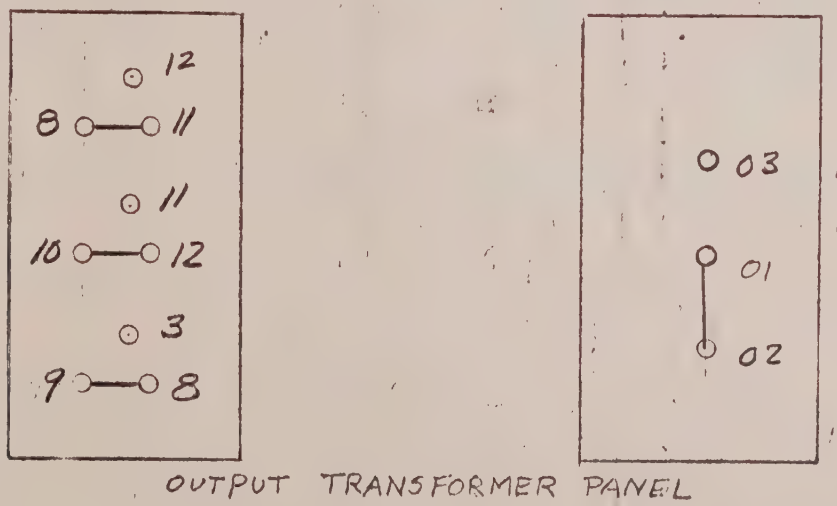
Output Transformer Connections
A102 Power Amplifier



Note: this pa
on master
A102 only;
omitted on
slave A102

Connections for Dual A102 s

Note: Also jumper interlocks to slave A102 on terminal strip; see system schematic



Note: Master
A102 only;
slave A102
not operable
in single mo

Connections for Single A102

III. Control Console.

The Control Console contains the Automatic Shaker Control, the Adjustable Power Supply for the shaker field, the Dial-A-Gain (If this system does not include a Dial-A-Gain, refer to Page D-1A.) and the control circuitry, pilot lights, driver coil and field coil ammeters, interlocks and the system "on-off" switch. All operating controls are located in the panel above the writing surface of the Console.

A. Automatic Shaker Control

The Model BK 1039, BK 1008 or BK 1025 Automatic Shaker Control is manufactured by Bruel and Kjaer. The instruction booklet on this unit is included in the enclosures which gives a complete description and specification of this unit. In summary, this unit includes the following features and components. (Some newer systems are furnished with the Model BK 1008 or BK 1025 instead.)

1. The Oscillator

The Oscillator originates the signal voltage which is fed to the Power Amplifier, which in turn causes an alternating current to flow through the driver coil of the shaker. The driver coil current causes the shaker table motion. Hence the frequency and magnitude of shaker table motion is controlled by the frequency and voltage generated by the oscillator.

The Oscillator may be used manually by the independent adjustment of the frequency dial to any frequency from 5 to 5000 cps (a second range from 5005 to 10,000 cps is also included) and the output voltage control knob giving in turn the shaker frequency and amplitude of motion respectively.

The oscillator also may be used with automatic sweeping between settable high and low frequency limits and with an adjustable sweeping rate.

2. The Automatic Level Control.

Constant set values of shaker table displacement, velocity and acceleration can be maintained during frequency sweeping by using the electronic servo control. In addition to holding displacement, velocity or acceleration constant the control can be set to automatically transfer from constant displacement control to constant acceleration control with increasing sweep frequency with the transfer occurring at a manually settable frequency between 10 and 500 cps. Also the control can be set to automatically transfer from constant velocity to constant acceleration. The automatic level control adjusts the magnitude of the oscillator output voltage fed to the power amplifier to account for variations in system frequency response due to resonant characteristics of the items mounted on the shaker table and the inherent shaker system response itself.

If desired, the frequency may be varied manually or held at a fixed frequency while the automatic level control maintains the set value of displacement, velocity or acceleration, or an automatic transfer at a set frequency from displacement to acceleration control, or velocity to acceleration.

3. The Vibration Meter.

The automatic shaker control panel includes an indicating meter which in addition to showing the value of the oscillator output voltage is arranged to indicate displacement, velocity or acceleration of the shaker table motion in conjunction with the accelerometer submerged in the shaker table and the Dial-A-Gain in the Control Console.

A function selector switch is used to select displacement, velocity or acceleration indications and range switches provide convenient scale readings for a wide range of amplitudes of each function.

B. Shaker Field Adjustable Power Supply

The Adjustable Field Supply is provided to give more flexibility in system operation. If full rated generated force is not required for a particular test, the operator may reduce the field current in order to minimize the already low magnetic leakage flux at the table surface or increase the obtainable low frequency table displacements.

Field adjustment is by means of a knob in the lower panel of the Control Console. Field current is indicated in the field ammeter. The field adjustment knob alters the a-c voltage applied to the silicon rectifier bridge by means of an adjustable auto transformer as shown on the system schematic wiring diagram.

C. Dial-A-Gain

The Dial-A-Gain is a multipurpose instrument which allows monitoring acceleration from any piezoelectric accelerometer. It includes a high impedance cathode follower input and a variable gain amplifier.

The front panel output from the Dial-A-Gain is automatically adjusted to 1 volt rms/g peak when the front panel sensitivity dial is set to the sensitivity of the accelerometer (mv/g) plus cable being monitored. The rear panel connection output from the Dial-A-Gain to the BK 1025 is automatically adjusted also to either 1 volt per g or 10 mv per g depending on the system. (Refer to the BK 1025 schematic furnished with the system to determine which output is furnished.) Thus it can be used to minitor the built-in accelerometer or any accelerometer mounted on the table or specimen. In order to make the built-in vibration meter in the Model BK 1025 read correctly with any accelerometer, all that is necessary is to adjust the sensitivity dial on the panel to correspond to the sensitivity of the accelerometer plus cable being used. An alternate method of checking this calibration is discussed in Section E - operating considerations "table accelerometer sensitivity spot check".

DIAL-A-GAIN

Model 601R-A Ser. 230

Operating Instructions

1 - Connect to 110V 60 cycle line, turn on switch.

2 - Connect to any piezoelectric accelerometer with a sensitivity between 1 to 100 mv/g to the input connector. No external cathode follower necessary.

3 - Set the range switch to the appropriate range corresponding to the accelerometer used.

4 - Set the Sensitivity Dial to the sensitivity of accelerometer plus cable combination being used. The number in the window should be between 1 and 10. Lock the dial by rotating the black lever in the upper right quadrant clockwise. Note that the sensitivity units are mv (rms) per "g" (peak).

5 - The instrument is now ready for use, providing an output of 1 volt (rms) per "g" (peak). Some models provide other outputs.

6 - The Model 602 Dual Channel includes a switch which allows monitoring either the right or the left channel via the right hand output jack. When the switch handle is to the left, the left channel is connected to the right hand jack. When the switch handle is to the right, the channel is connected to the right jack. The left jack is connected to the left channel at all times.

Notes:

1 - Sixty Cycle Pickup.

The hum level in the output may vary from one test setup to the next depending upon ground loops, etc. If low level acceleration measurements are being made the hum level should be minimized. The Dial-A-Gain includes a hum level adjusting potentiometer. It is accessible thru the snap out plug hole in the bottom of the case. Connect the accelerometer to the input and monitor the output on an oscilloscope. Adjust the potentiometer for minimum 60 cycle output preferably with a non-metallic screw driver.

Often the hum level can be reduced by reversing the line plug.

2 - To avoid ground loops, it is recommended practice to electrically insulate the accelerometer from the specimen. Accelerometer manufacturers market threaded insulating studs for this purpose.

3 - For observing transients in excess of 100g the overall gain can be reduced by some convenient factor. This of course changes the output sensitivity by the same factor.

4 - The input connector may be easily changed to allow use of other cables or connectors.

5 - DO NOT LOOSEN OR REMOVE THE SENSITIVITY DIAL from its shaft mounting. Doing so will alter the calibration.

6 - To open the case rotate the two screws in the rear a half turn counter clockwise and slide front panel assembly out of case.

Rev. A.

PERIODIC CALIBRATION PROCEDURE FOR MODELS

601, 602, 603

AND 606

1. Check open loop gain.

   a. Set Sensitivity Potentiometer to maximum CCW. Number in window should be zero and dial should read between 8 & 12.

   b. Connect oscillator to input and VTVM to output.
   Set frequency to 500 Hz.

   c. Adjust output to 50 with range switch in 10-100 position.

   d. Measure input voltage. Should be less than 0.05.

2. Set Sensitivity Dial.

   a. Set frequency to 500 Hz.

   b. Set dial at 10.0 and adjust output to 5 volts on voltmeter.

   c. Rotate Sensitivity Dial CCW until output reads 50 V.
   Read Sensitivity Dial.

      1. If sensitivity dial reads less than 1.0, change V2. (6AN8) Repeat b and c.

      2. If sensitivity dial reads less than 1.0, or more than 1.0 after changing the 6AN8, offset the dial the number of divisions necessary to give a dial reading of 1.0 with 50V output. To change dial setting, first short input. Then rotate the dial (CCW if setting is greater than 1.0 and CW if setting is more than 1.0) until it stops. Loosen set screw in knob maintaining the drag on potentiometer shaft and offset number of divisions necessary. Ex. If dial reads 1.02 to give 50V output rotate max CCW, note dial reading and then loosen and shift 2 divisions.

      3. Repeat b and c until meter and dial agree.

   d. NOTE: The dial when rotated fully clockwise should be offset approximately 10 divisions ± 2

3. Check Range Switch.

   a. Set dial at 10.0

   b. Set range switch to 1-10

c. Set output to 50V

d. Rotate range switch to 10-100

e. Output should be 5V.

4. Check Maximum Drive.

a. Set range switch at 10-100

b. Set Sensitivity dial @ 1.0.

c. Set output to 100.

d. Connect scope to output and check if distortion present @ 50 Hz, 500 Hz, 5000 Hz.
Shunting the screen bias resistor of the pentode allows shifting the output operating point and thereby eliminating clipping if present.

5. Set Overall Gain @ 500 cps.

a. Set sensitivity dial @ 10.0

b. Range Switch @ 10-100

c. Set output to 10.0 on voltmeter

d. Measure input. Should be 1.0. If input is less than 1.0 shunt 200 K precision resistor in feedback path with a 22 meg resistor, if input is 1/2 division (1%) low, 10 meg if 1 division (2%) low.

e. Repeat a to d at 5 kHz and 5 Hz. Input should be $\pm$ 2%.

6. Frequency Response

a. Set output to 10.00 and frequency to 500 Hz. Insert 500 mmfd capacitor in series with input. Output should not drop more than 1%. This is due to input capacitance of C.F.

b. Repeat @ 5 Hz. Output should not drop more than 1-1/2%.

7. Meter Calibration (Model 606M)

a. Set sensitivity dial to 10.0

b. Set sensitivity range to 10-100

c. Adjust oscillator until Dial-A-Gain output as shown on the VTVM, is 10.0 volts rms (at 500 Hz).

d. Set meter range switch to 10 full scale and turn meter adjust potentiometer until meter reads 10.

e. Short the input to the Dial-A-Gain. The meter should come to rest at zero, after allowing approximately 30 secs. for pointer to settle. If the pointer does not come to rest at zero adjust the screw on the front of the meter until it does.

f. If front panel zero adjust screw had to be set, repeat steps d and e.

8. Check noise level with accelerometer attached to input and chassis covers on. Accelerometer must be mechanically isolated during this check.

a. Set range switch 1-10

b. Set dial to 10

c. Measure noise on RMS meter. For an accelerometer with a sensitivity between 8 and 10 mv/g, the noise level should be less than 10 mv(rms). Adjust the hum level potentiometer for a minimum reading. If noise level is higher than 10 mv after hum adjust, change input 12 AX7. We recommend AMPEREX or MULLARD for minimum noise in this circut. NOTE: Some instruments use a CK5755 input stage.

Note: Always set Hum Level Pot with sens. range switch in position required by your accelerometers.

TO OPERATE SYSTEM

1. Turn Wall Power On.

2. Turn Amp. Gain Switch down (full CCW) located on master preamp. chassis. With dual preamp. chassis, the Amp. Gain switches on both preamp. chassis must be down.

3. Turn the oscillator gain down (full CCW). The oscillator may be any of the BK types 1019, 1008 or 1025, or SD104.

4. Push the "Preamp On" button on the meter panel. The "Preamp On" light should light, the console fans should start, and the console instruments will come on.

5. After a minute or two time delay, the "Standby" light should light. Push the "Operate" button to apply the plate voltage to the output tubes. The shaker field will come on (if the powerstat is turned up), the shaker blower will start and the "Operate" light should light. Note that the "Operate" button must be held down until the blower pulls in the air switch, on systems with air switches in the shaker.

6. The shaker field current can be adjusted after a warmup period to the rated current. Normally this powerstat setting is not disturbed in turning the system on or off.

   Rated Field Current is 34 amps.

7. The system is now ready for operation. To drive system, turn up the "Amp. Gain" on the master preamp chassis and operate the oscillator gain and frequency control as required. The "Amp. Gain" on the slave preamp. may be left down. See following pages for oscillator operation.

8. Rated performance for this system is given on Curve Q 370 at the rear of this manual. Overdriving the system beyond ratings will trip a protective device, putting the system on standby.

9. At any time the system can be put on standby operation by pushing the "Standby" switch. This removes the high voltage from the output tubes, and turns off the shaker field and the shaker blower. However, the instruments and output tube filaments stay on, permitting restartup without a time delay cycle. At any time, operation may be resumed by pushing the "operate" button. The "Amp. Gain" switch must first be turned down or the Operate light will not light.

10. IMPORTANT - The shaker blower rotation should be according to the arrow on the blower. It should be checked on initial startup and whenever the system is relocated, or the three phase power line is changed.

TO OPERATE SYSTEM

A. Manually Controlled

1. Calibrate the BK 1025 Oscillator following the instructions given in B-K operating manual page 29 under heading "Calibration of Frequency Scale". If the thumbscrews Sa and Sb shown in figure 5.1 page 30 interfere with positioning of the oscillator dial, loosen and relocate as necessary.

2. Turn "Amplifier Gain" knob full clockwise.

3. Set "Meter Switch" to "Vibration Level".

4. Set "Function Selector" to displacement, velocity or acceleration, whichever quantity is desired on the vibration meter.

5. Set the range switch for "Displacement-Velocity" or "Acceleration" as required to give the desired full scale reading on the vibration meter. The "Acceleration" range switch should be positioned to use the "Acceleration Generator" rather than "Velocity Generator" positions. The "Displacement Velocity" range switch should be positioned to use the "Acceleration Generator" positions.

6. Set compressor speed switch to "off".

7. Set the oscillator dial to the desired frequency and slowly turn the "Output Voltage" knob clockwise until the desired level of vibration is present at the shaker table and is indicated on the vibration meter. The "Amplifier Gain" control knob on the console panel may be used in conjunction with the "Output Voltage" amplitude control to limit the drive at full rotation or to act as a fine control of amplitude.

B. Automatically Controlled.

See pages: D-12 and D-12-1, also the Bruel and Kjaer Instruction Manual.

TO OPERATE SYSTEM (continued)

C. To Stop System

The system "on-off' switch will completely shut off the system when placed in "off" position regardless of whether operating manually or automatically. It is good practice to turn the "Amplifier Gain" and "Output Voltage" knobs full counter clockwise prior to system shut down. (When operating under automatic frequency cycling observe shut down procedure given on page D 12).

D. Operation with Reduced Field Power

Larger table displacements may be obtained at frequencies below 100 cps by reducing the field power in those cases where rated generated force is not required as compared to operating with full field power. By reducing the field power, less back generated voltage is generated in the driver coil for a given coil velocity resulting in larger table motions with a given terminal voltage from the power amplifier.

Two types of operation may be considered: (a) Fixed Frequency and (b) Automatic Frequency Cycling.

Fixed Frequency

With the load in place on the shaker table adjust the frequency to the desired value and with full field power, introduce a moderate drive by increasing the "Output Voltage" on the Automatic Shaker Control. Note the value of displacement on the vibration meter. Slowly reduce the field power by turning the field power control knob counter clockwise watching the displacement indication on the vibration meter. If back generated voltage is an important part of the shaker impedance at this operating condition, the displacement measured will increase. Reduce the field until the displacement goes through a maximum value. Adjust the field for the maximum value of displacement. With this field setting adjust the "Output Voltage" knob for the desired displacement, keeping within the system operating limits as described in Section E, or as shown on the system performance curve.

Automatic Cycling

When covering a broad frequency range two conditions must be met when reducing the field. (a) The required force must be obtainable in the high frequency range limiting the amount that the field can be reduced and (b) The required displacement in the low frequency determines the optimum field for this part of the operation.

By manually sweeping the frequency range slowly and keeping the amplifier operation within limits as described in Section E, the proper field power adjustment can be obtained on a cut and try basis. Following the adjustment of the field, automatic operation may be established according to the procedures of Section D above.

V. To Rotate Shaker on Trunnions

Loosen the two trunnion clamp screws on each base pedestal and rotate shaker body to the position desired. See Figure D2. Retighten Trunnion clamp screws after positioning shaker.

VI. To Lockout Trunnion Vibration Isolation

To lock out vibration isolation, tighten each of two lockout screws in each base pedestal. To float shaker body on resilient mounts, loosen lockout screws.

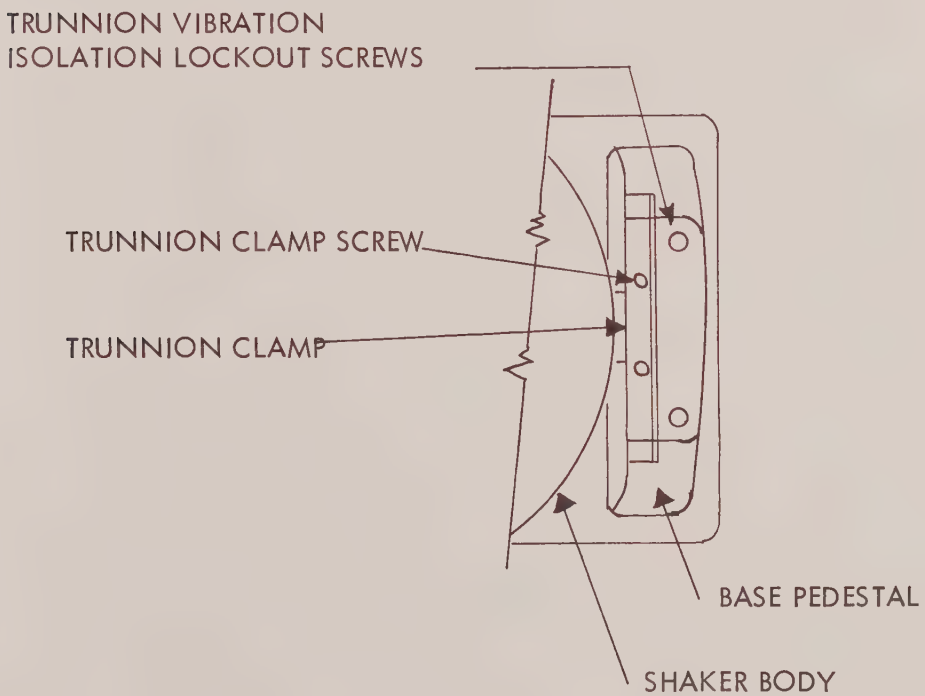


FIGURE D-2

BK 1008, 1025 Automatic Cycling

Abbreviated Instructions

(For complete discussion, see BK Manual)

1. Set Control Knobs per sketch page D-12-1 before startup. A summary of Knob Settings follows:

   a. Power on
   b. Meter Switch to "PRESET"
   c. Operation Switch to "Scanning Off"
   d. Frequency range to "5 - 5000"
   e. Compressor speed to "Off"
   f. Output Switch to "High Pass" for light loads, "Linear" for heavy loads
   g. Output Voltage down (CCW)
   h. Accel. and Displ. levels down (CCW)
   i. Function Selector to "Auto D-A"
   j. Vel. Gen. Response to "Flat"

2. Beat frequency with 60 cycles (Be sure to return meter switch to PRESET)

3. Set freq. limits and crossover freq.

4. Set range switches, Accel. and Displ. (Use ACCEL GEN)

5. Amp. Gain Switch located on console panel turned full on (CW)

6. Compressor speed is turned on to 10-10-30-100-300.

7. Set freq. above crossover and adjust "Accel level" Control for desired g level on meter.

8. Set freq. just below crossover and adjust "Disp level: for desired displacement on meter.

9. Switch to Standby.

10. Turn Output Voltage Max CW.

11. Switch to Vibration Level. System should slowly increase vibration level until desired displacement is reached.

    CAUTION: From this point on, servo is turned on. DO NOT CHANGE RANGE SWITCHES WHEN SERVO IS ON.

12. Adjust Output voltage control near the crossover frequency for 0 - 5 dB compression.

13. Switch to Standby and set freq. to low limit.

14. Switch to Vibration Level and Scanning On. Select desired sweep speed.

TO STOP a test at any point, turn OPERATION SWITCH to "Standby"

From Auto Control; To Turn Off

1. Scanning Speed Off
2. Displ. and Accel. Levels down (CCW)
3. Output Voltage down (CCW)
4. Compressor function off.

E. OPERATING CONSIDERATIONS

1. Calculation of rated acceleration of shaker table for various table loads.

$$\text{Table acceleration (g)} = \frac{F}{W + W}$$

where:

F = shaker rated force

W = nominal bare table weight

W = total table load including test item, attaching fixture, bolts, etc.

2. Operation with reduced field power. (Not applicable to systems with fixed field).

At frequencies below the flat acceleration portion of the curves shown on the System Performance plot, the velocity of shaker table motion becomes important. The velocity of the driver coil in the high density magnetic field generates a back emf which opposes the voltage supplied by the Power Amplifier. Hence in this frequency range, table motion becomes limited by velocity rather than acceleration. In some cases where the full rated shaker force is not required or generated at the velocity limit, larger table motions can be obtained by lowering the field coil current and the back generated emf. The field current is adjusted by turning the Powerstat knob in the lower control panel. The optimum field current for maximum table displacement is dependent upon the load on the table and the operating frequency. Hence, it is difficult to state limits of performance under these conditions without being severely restrictive. The operator should avoid over-driving the power amplifier or contacting the stroke limiting snubbers in the shaker under these conditions. A rough indication of amplifier overdrive is the point of abrupt deterioration of the acceleration wave-form. Optimum field current can be readily determined at a given operating frequency by placing a moderate amplitude on the system with full field. With the amplitude control unchanged, reduce the field current until maximum table motion is observed. Holding this field, adjust amplitude control until desired displacement is obtained.

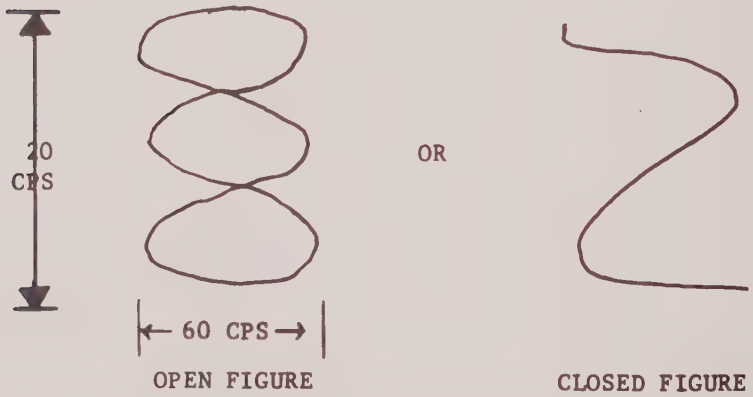
3. Table accelerometer sensitivity spot check.

This check is suggested because it is so easily performed and at the same time checks the associated measuring instruments. Specific recommendations are:

a. Attach an accurately ruled set of two parallel lines of known spacing or simply black plastic electrical tape * to a vertical, smooth surface of the item attached to the shaker table. In the case of the plastic tape, measure the width of the tape with a Micrometer before removing from the roll.

b. Connect the output of the Dial-A-Gain to a VTVM and the Y axis of a Cathode Ray Oscilloscope. Connect a low voltage 60 cycle signal voltage from the power line to the X axis of the CRO. This provision is contained in the controls of many Cathode Ray Oscilloscopes. (X axis connection is unnecessary if an electronic counter is available).

c. Adjust the operating frequency to exactly 20 cps while using a moderate level of amplitude. 20 cps to good accuracy results when the CRO Lissajous Figure is stationary and of the form illustrated.



OPEN FIGURE CLOSED FIGURE

d. Adjust table displacement to exactly that of the parallel line spacing or the tape width. Use a flashlight for illumination if necessary to avoid the stroboscopic effects of fluorescent lights.

e. The shaker table acceleration is calculated using,

$$g = \frac{\frac{d}{2} \times 4\pi^2 \times f^2}{386} = 20.4\, d \quad \text{FOR } f = 20 \text{ Hz}$$

where d = peak to peak displacement in inches.

f = Hz (cycles per second)

* The parallel lines are preferred to the solid tape in order to avoid the penumbra effect.

4. Accelerometer cable length effects.

The piezoelectric type accelerometer is an electrical charge generator. The voltage measured depends upon the capacitance connected to this charge generator. The low noise accelerometer cable used has capacitance which is not insignificant in terms of the capacitance of the accelerometer itself. Hence, the apparent accelerometer sensitivity as measured at the end of the cable stretching between the accelerometer and the input to the Dial-A-Gain or other high impedance device depends upon the characteristics of the cable and its length.

The accelerometer mounted in the shaker table is connected by several lengths of cable to the Dial-A-Gain. The system is furnished with a calibration sensitivity $E_{cal.}$ which includes the capacitance of the cables furnished with the system. Figure 1 below indicates the cables and the various capacitances.

The values of sensitivity and capacity for this system are as follows:

$E_{cal.}$ = 8.07 mv rms/g peak (THIS IS THE SENSITIVITY THAT THE DIAL-A-GAIN SHOULD BE SET TO, for the cables supplied with the system)

C_A = 1357 pf. (the internal capacitance of the accelerometer)

C_1 = 187 pf. (capacitance of cable inside the shaker)

C_2 = 760 pf. (capacitance of cable between shaker and Dial-A-Gain)

C_3 = 6 pf. (input capacitance of Dial-A-Gain)

$C_{cal} = C_A + C_1 + C_2 + C_3$ = 2310 pf.

If additional cables are inserted, or if another accelerometer on top of the specimen is substituted, then a new sensitivity E must be dialed on the Dial-A-Gain. The general formula relating sensitivity and cable capacitance is discussed on the following pages.

ACCELEROMETER CABLE LENGTH EFFECTS

A. Voltage Measuring Instrument

The piezoelectric type accelerometer is an electrical charge generator. The voltage measured depends upon the capacitance connected to this charge generator. The low noise accelerometer cable used has capacitance which is not insignificant in terms of the capacitance of the accelerometer itself. Hence, the apparent accelerometer sensitivity as measured at the end of the cable stretching between the accelerometer and the input to the Dial-A-Gain or other high impedance device depends upon the characteristics of the cable and its length.

B. Charge Measuring Instruments

However, if the instrument used is a charge amplifier such as the Unholtz-Dickie Dial-A-Charge then no correction for cable lengths is necessary. Simply dial the dalibrated charge sensitivity of the accelerometer and the unit is in calibration, independent of cable lengths.

C. The relationship between the charge sensitivity and the voltage sensitivity is as follows:

$$Q = EC_t$$

where Q is the charge sensitivity of the accelerometer in picocoulombs PEAK per g PEAK

E is the voltage sensitivity in mv PEAK/g PEAK

C_t is total capacitance of accelerometer, cables and input to cathode follower voltage amplifier

Example: A particular accelerometer has the following charge sensitivity. The voltage sensitivity with a 10 ft. cable is desired.

$Q = 11.9$ picocoulombs PEAK per g PEAK

$C_t = C_A + C_2 + C_{IN}$

$C_A = 784$ pf, accelerometer internal capacitance

$C_2 = 294$ pf, cable capacitance

$C_{IN} = 6$ pf, input capacitance of Dial-A-Gain

$C_t = 784 + 294 + 6 = 1084$

$$E_{corr.} = \frac{Q}{C_t} = \frac{11.9}{1084} = 11.0 \text{ mv PEAK/g PEAK}$$

$$E_{corr.} \doteq \frac{11.0}{\sqrt{2}} = 7.78 \text{ mv RMS/g PEAK}$$

If this accelerometer and cable were used with a Dial-A-Gain voltage amplifier, the number 7.78 would be dialed on the Dial-A-Gain and the system would be in calibration.

D. Some manufacturers give the voltage sensitivity of the accelerometer without any cables added. This is known as the open circuit sensitivity. It includes only the internal capacity of the accelerometer, and is equal to:

$$E_{o.c.} = \frac{Q}{C_A}$$ where C_A = capac. of accelerometer

Q = charge sensitivity of the accelerometer

In this case, to obtain the voltage sensitivity into the Dial-A-Gain with a given cable capacitance, the following correction must be made:

$$E_{corr.} = E_{o.c.} \quad \frac{C_A}{C_A + C_2 + C_{IN}}$$

where C_2 is cable capacitance

C_{IN} = Dial-A-Gain input capacitance

Example: A particular accelerometer has an open circuit voltage sensitivity of 27.52 mv PEAK per g PEAK, an internal capacity of 1618 pf. Find the voltage sensitivity when used with a 313 pf cable capacitance and a Dial-A-Gain input capacitance of 6 pf. See Fig. 1.

$$E_{corr.} = 27.52 \quad \frac{1618}{1618 + 313 + 6} = 23.00 \text{ mv PEAK/g PEAK}$$

$$\text{OR } E_{corr.} = \frac{23.00}{\sqrt{2}} \approx 16.3 \text{ mv RMS/g PEAK}$$

This is the new sensitivity that should be set on the Dial-A-Gain

E. Some manufacturers give the voltage sensitivity of the accelerometer including a particular external cable capacitance. If this same cable is being used, then no correction factor is necessary, and this voltage sensitivity can be dialed directly into the Dial-A-Gain (neglecting the small Dial-A-Gain input capacitance).

Two other possibilities exist; 1 - additional cable length is used or, 2 - a shorter cable is used than the one that the voltage sensitivity is given with.

If additional cable length is used, then the following correction must be made:

$$E_{corr.} = E_{known} \quad \frac{C_A + C_{cal}}{C_A + C_{cal} + C_2 + C_{IN}}$$

where E_{known} = voltage sensitivity with the stated external capac.

C_A = Accel. Capac.

$C_{cal.}$ = Stated external capac.

C_2 = Capac. of the added cable

C_{IN} = input capac. of Dial-A-Gain

Example: A manufacturer gives a voltage sensitivity with an accelerometer of E_{known} = 7.80 MV RMS/g PEAK, including $C_{cal.}$ = 300 picofarads for 10 feet of external cable capacitance. The internal capacitance of the accelerometer is C_A = 732 pf.

Case I. Find the new sensitivity if an extra 25 foot cable is added to the original 10 foot cable (300 pf). See Figure 2. The 25 foot cable capacitance is 760 picofarads.

$$E = E_{known} \frac{C_A + C_{cal.}}{C_A + C_{cal.} + C_2 + C_{IN}}$$

$$E = 7.80 \quad \frac{732 + 300}{732 + 300 + 760 + 6}$$

$E = 4.48$ mv RMS/g PEAK

(This is the new sensitivity that should be set on Dial-A-Gain)

Case II Find the new sensitivity if only a short cable is used which has less capacity than the one used for the calibration. In figure 3 the actual cable used is a 6 foot cable with 180 pf of capacitance.

where E_{known} = voltage sensitivity with the stated external capac.

C_A = Accel. Capac.

$C_{cal.}$ = Stated external capac.

C_2 = Capac. of the shorter cable

C_{IN} = input capac. of Dial-A-Gain

$$E = E_{known} \frac{C_A + C_{cal.}}{C_A + C_2 + C_{IN}}$$

$$E = 7.80 \quad \frac{732 + 300}{732 + 180 + 6}$$

$E \doteq 8.76$ mv RMS/g PEAK

Note that this new sensitivity is larger than the original calibrated sensitivity due to the decrease in the capacity loading the accelerometer.

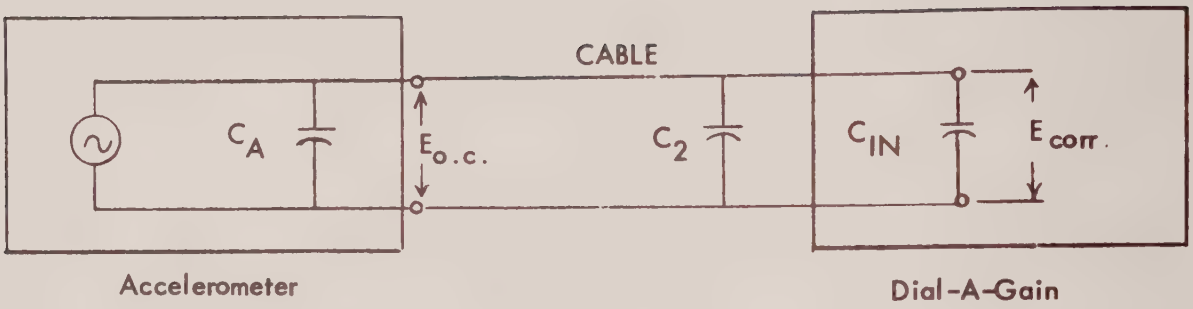


FIG. 1

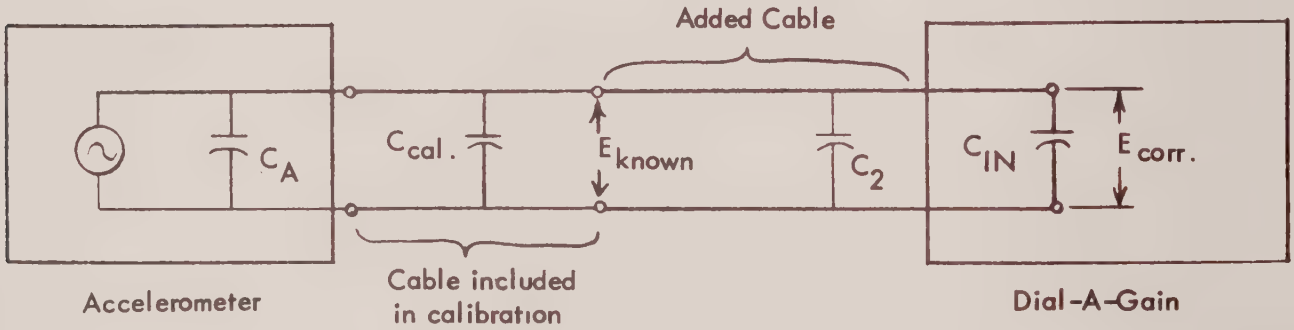


FIG. 2

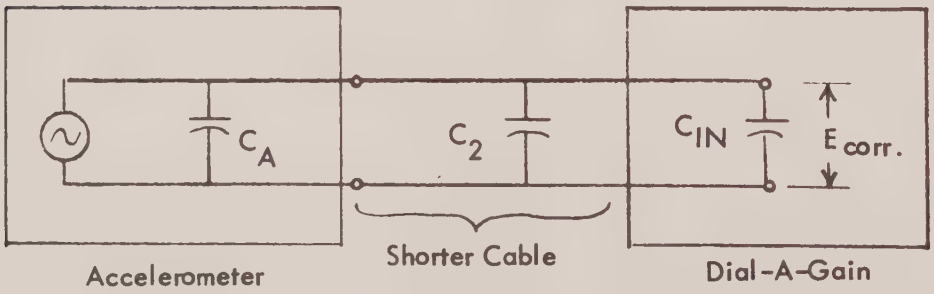


FIG. 3

F. MAINTENANCE

In general, very little maintenance is required for the vibration testing system. Depending upon local conditions and the extent of system usage, attention should be given to the following:

1. Inspect and clean or replace if necessary

   a. Supply water line strainer[1] (water cooled shaker)
   b. Control cabinet blower air filter in accordance with instructions on filter[2] (check every 40 hrs.)
   c. Air inlet screen on shakers including cooling blowers. blowers.

2. Add 2 drops of light oil to cabinet blower motor once every 6 to 12 months.

3. Inspect flanged table attaching inserts. Helicoil thread inserts should end at bottom of wrench slot. If helicoil insert rotates out of this position the threads may be damaged on subsequent attaching bolt tightening. A special wrench is shipped with the system for tightening or removing the flanged insert. It is taped to the shaker electrical power cable. To use the wrench, engage the key of the wrench in the slot in the insert. Attach the wrench to the insert using a screw passing through the wrench and engaging the threaded hole in the insert. Rotate the wrench as required. Spare inserts are available from the factory at moderate cost.

If this system will generate rated force throughout the frequency ranges with good acceleration waveform with no load or rigid mass load on the table, all parts of the system can be assumed to be in good working order. If for any reason the cover of the shaker is to be removed or the accelerometer replaced, the following should be considered:

Shaker Cover Removal

1. Remove all round head attaching screws on top of cover.

2. Note position of accelerometer cable connector so cover may be re-installed without rotation from this position.

---

[1] Cartridge P111-3 or P118-1 25 micron Cuno Engineering Corporation Meriden, Connecticut.

[2] EZ Kleen Air Filter Size 12 1/8 x 12 1/8 Research Prod. Corp., Madison, Wisconsin.

3. Slowly raise cover, careful not to pull accelerometer lead attached to it.

4. Position cover for easy access to accelerometer cable connection to cover bulk-head connector and detach.

5. Lift off cover.

Accelerometer Removal From Shaker Table

1. Remove shaker cover as directed above.

2. Remove all tape attaching accelerometer cable on leaf spring element and table casting.

3. Using special wrench supplied with shaker, screw wrench to center table insert as described above. Unscrew center insert to which accelerometer is attached, rotating accelerometer cable at the same time to avoid twisting and damaging the fragile cable. When insert is free of the table, lift from the table drawing accelerometer cable out with it.

4. Remove accelerometer cable from accelerometer.

5. Remove accelerometer from the insert.

Blower Screen Maintenance

1. It is extremely important to check the blower intake screens at least once a month to be sure they are not clogged with dust or dirt. Brush off all accumulated dust on screen. Failure to do this can lead to overheating the driver coil and burning it out.

Water Filter Maintenance

Caution: For water cooled systems with Cuno Filters, it is extremely important when replacing the filter cartridges to be sure to replace the metal seal. This is a small metal disc which fits in the bottom of the plastic bowl and bears against the replaceable cartridge. Failure to replace this metal seal renders the filter inoperative and can lead to plugging the shaker system with dirt. See SK 1208.

UNHOLTZ-DICKIE CORPORATION

MODEL 160-8 SHAKER

PARTS LIST

PART NO.	ITEM	QUAN.PER SHAKER
D-8305	Web	1
910-1607	Hub	1
D-8309	Flanged Disc	1
D-8311	Top Disc	1
910-2513	Top Cylinder	1
D-8315	Pie	1
910-3617	Shear Mount	2
A-8323	Upper Coil Support Block	4
A-8346	Spring Clamp Spacer	4
A-8347	Spacer, Short EPRA	4
A-8348	Stainless Spring End Clamp Threaded	2
A-8349	Shear Mount Adapter	2
A-8352	Short EPRA	4
A-8355	Long EPRA	4
A-8320	Air Lower Field Coil	1
A-8321	Air Upper Field Coil	1
D-8322	Rim	1
B-8363	Spring Assy., Shorter	2
D-8332	Hood	1
910-1623	Insulating Block, Upper Clamp	8
910-1624	Steel Block, Upper Clamp	8
910-1625	Side Block, Upper Clamp	8

UNHOLTZ-DICKIE CORPORATION

MODEL 160-8 SHAKER

PARTS LIST

PART NO.	ITEM	QUAN. PER SHAKER
910-2591	Switch Block Down	1
910-2653	Switch Block Spacer	1
910-2533	Hex	12
910-1634	Screen	1
910-1637	160 Base	1
910-1638	Base Spacer	2
910-1038	Pedestal	2
910-1640	Trunnion	2
910-1041	Trunnion Clamp	2
910-2548	Bumper Upstroke, Bonded	2
SK-1034	Insert Wrench	1
910-1649	Outer Spring End Clamp	28
910-1655	EPRA	8
910-1657	Upper Suspension Block	4
910-1656	Lower Suspension Block	8
910-1659	Junction Shell Block	1
910-2527	3/8-16 Insert Small	12
910-2528	3/8-16 Insert Large	1
910-2564	Insert Spacer Small	12
910-2565	Insert Spacer Large	1
910-1662	Current Spring Assy Large Hole	2
910-1683	Ground Spring Assy. Small Hole	1
910-1663	Spring Assy.	3

UNHOLTZ-DICKIE CORPORATION

MODEL 160 & 160-8 SHAKER

PARTS LIST

PART NO.	ITEM	QUAN. PER SHAKER
910-1622	Suction Manifold	1
Flexhaust	4" Dia. 20 ft. Hose Cuffs on each end	1
Flexhaust	Clamps for above	2
PW-12	Hartzell Blower - Totally enclosed Motor with Ball Bearings	1
910-1681	Blower Duct Adapter 4"	1

Fixture Design

Some Comments

Vibration test fixtures come in such a large variety of sizes and shapes that it is difficult to give general statements that can be useful for a particular design. However in working with our customers who are newcomers to the field of vibration, we have found a common problem which we feel warrants pointing out. Customers with long experience in fixture designs and applications will of course be aware of the problem to be discussed here and will have overcome it.

Many newcomers approach fixture design from the viewpoint of static strength and stiffness. The fixture and load weight are estimated and multiplied by the 'g' level of the test. This yields the force transmitted. This force is usually quite modest in terms of static strengths so that the designer then proceeds to clamp the specimen to the fixture and the fixture to the shaker table with a few bolts and clamping sections which are entirely adequate to cope with these low static forces. This approach fails to account for the dynamic conditions that occur at the higher frequencies encountered in most vibration tests.

Usually when a fixture is designed with only static loads in mind, a very severe major resonance occurs within the frequency range of the test. The clamping and bolting arrangement, while adequate statically, turns out to be very soft or compliant when analyzed dynamically. In other words the mass of the test item and fixture is resonant on the soft springs consisting of the clamping arrangement to the shaker table.

There are at least two major objections to this resonant condition. The first is that the test item does not receive the correct 'g' level as controlled by the accelerometer in the shaker table. Due to the resonance, the 'g' level at the test item can be many times higher than the shaker 'g' read on the meter. This results in severe overtesting, sometimes damaging the specimen.

The second is that due to the resonance, there usually occurs a frequency where extremely high amplifier power is required to maintain constant 'g' at the shaker table. This can be observed by noting when the driver ammeter swings full to the maximum and pegs the needle. This results in severe overdrive, high distortion, shortened tube life, and blown fuses.

The cure is to design fixtures with the dynamic problems in mind. In practice, this means making the clamps and hold down bolts stiff relative to the masses involved, so that the resonance of the spring-mass system is as high as possible, preferably above the operating frequency.

A second cure is to control from an accelerometer located up on the fixture or test item. This is usually less convenient, for the accelerometer must be moved each time the fixtures are shifted on and off the table. It is sometimes the only solution, as for example, if the test item is so large that the resonance cannot be pushed above the operating frequency.

The following section describes some typical static fixture designs we have encountered, and the recommended changes to make them dynamically satisfactory.

Case I

The test items were small electrical components clamped to rectangular aluminum plates 5" x 5" x 1/2". These plates were then mounted on the fixture which was bolted permanently to the shaker table. The first design for the fixture was a welded box structure of 3/8" thick welded aluminum plates as in Fig. 1. It was impossible to run the tests because of the severe resonance below 1000 cps, and 'g' levels on the test items were over 10 times as great as measured by the shaker accelerometer. The solution was the redesigned fixture shown in Fig. 2. This fixture was solid cube of magnesium, with drilled holes to remove weight. Also more of the hold down bolts into the shaker table were utilized. The resonance for this new fixture was moved up over 2 Kc and no testing difficulties were found.

Case II

In this test the specimen fitted into a cubical aluminum fixture. The fixture then was fastened at four points to a 1/4 inch thick aluminum adapter plate. The adapter plate was fastened at four other points to the shaker table. This adapter plate was in effect a very soft spring and a severe resonance occurred. Two solutions were possible. The fixture could be redesigned to bolt directly to the shaker table, using more than four bolts if possible. The second was to redesign the adapter plate. It was made of magnesium, about 1" thick. It was tied to the shaker table using all 13 holddown bolts available on that shaker. Additional bolts were added from the fixture to the plate. Figs. 3 and 4 show the before and after for this case.

Summary

Some of the points brought out by the above cases are:

1. Use as many of the hold down bolts to the shaker as possible.

2. Use magnesium instead of aluminum. Magnesium weight is about 65% of aluminum. Plate thickness can be made much thicker and stiffer with magnesium.

3. Avoid thin plates that can act as leaf springs, instead use solid, smaller fixtures. Weight can often be kept down by honeycombing with drilled holes, without affecting stiffness.

4. Use a minimum of joints or mating members. The omission of an intervening adapter plate almost always increases stiffness.

5. Two flat mating surfaces can be helped by a layer of silicone grease on the mating surfaces. This grease results in an adhesive action similar to the oil on Johanson gage blocks. This is particularly effective at high frequencies.

6. Use as many bolts, as possible, spaced as close as possible in bolting specimen to fixture, and fixture to adapter plates.

7. The fixture weight should not be the maximum allowed by the system performance. By making the static weight somewhat less, it allows for the higher dynamic loads that occur around resonance frequencies.

Several of the following references are helpful on vibration theory and dynamics of structures. Some give formula for stiffness of plates, beams etc. which are useful in fixture design.

1. "Handbook of Shock and Vibration"; Harris McGraw Hill

2. "Mechanical Vibrations"; Den Hartog 3rd Ed. McGraw Hill

3. "Mechanical Vibrations"; Thomson, Prentice Hall

4. "Vibration and Shock Isolation"; Crede, Wiley

POOR DESIGN

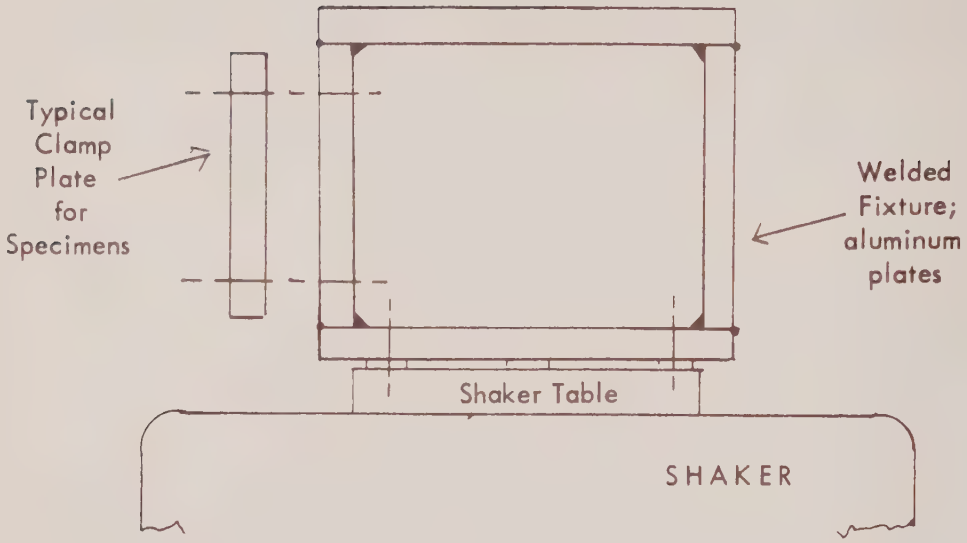


Fig. 1

REDESIGNED

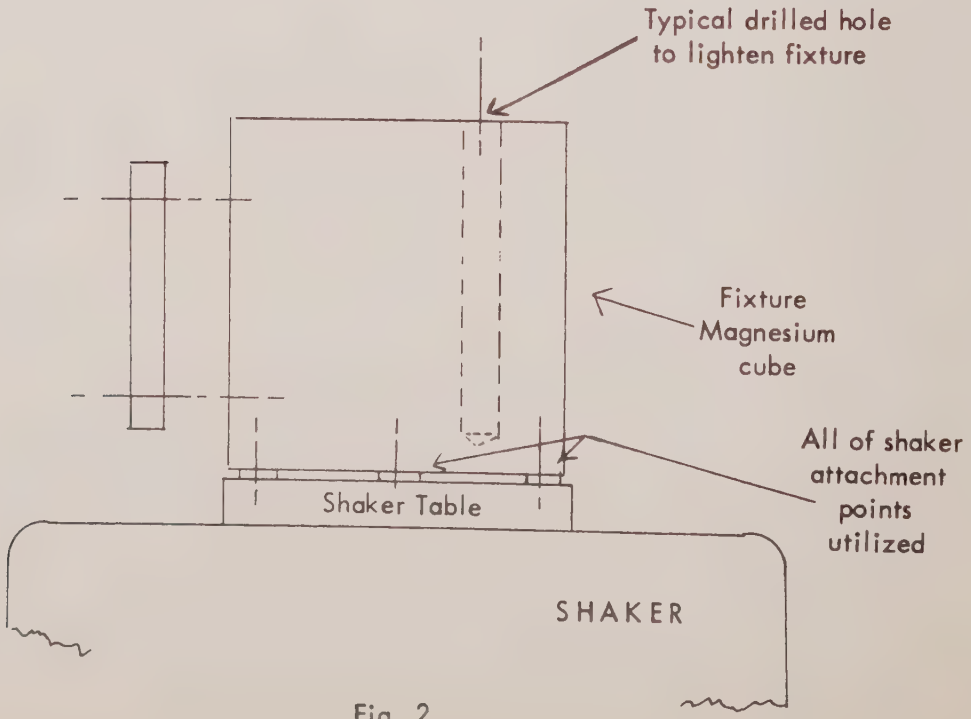


Fig. 2

POOR DESIGN

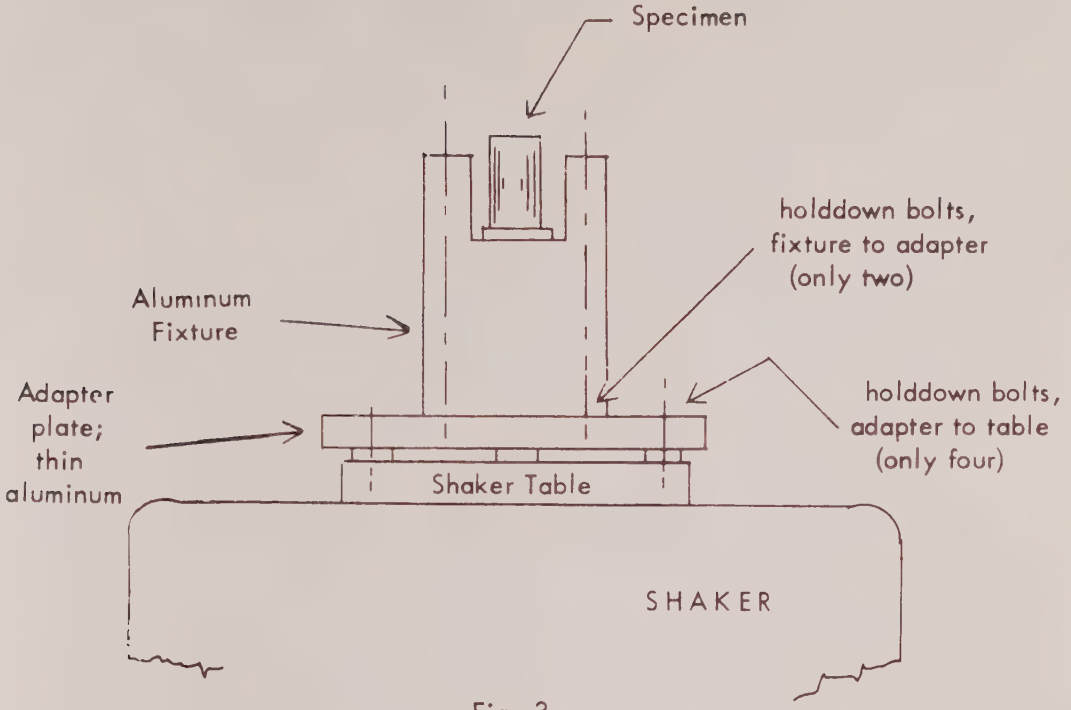


Fig. 3

REDESIGNED

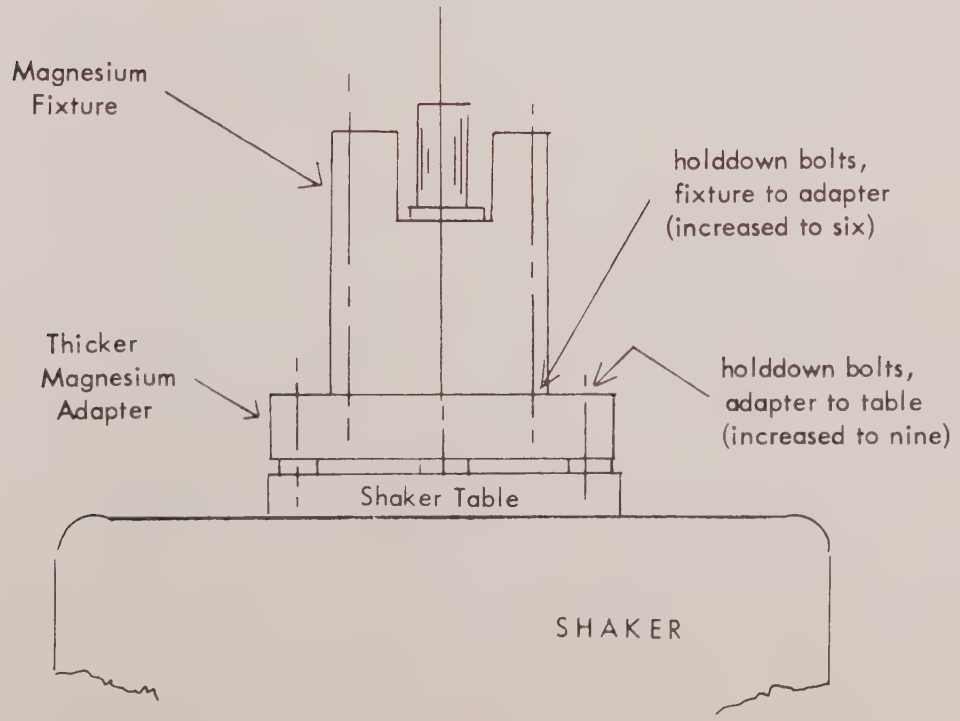


Fig. 4

TROUBLE SHOOTING THE SYSTEM

If the system is not operating correctly, and the difficulty is not apparent, some of the following checks should be made.

1. Check all the fuses, particularly in the power amplifier.

2. To eliminate some of the possible sources of confusion, the specimen and fixture should be removed from the shaker.

3. Next a check of the system should be made on manual control, with the BK Automatic Controller in the compressor "off" position. Then repeat the operation of the system to see if the malfunction still exists.

4. Connect an oscilloscope to the system with the following test conditions set up:

   a. Manual operation, free table with no load on shaker. (Compressor Off)
   b. Frequency set to 200 cps.
   c. Field current set to rated 3.4 amps D.C.
   d. Driver current set to test level 3.4 amps A.C.
   e. The acceleration "g" level should read 49 "g" using the shaker internal accelerometer.
   f. Check the output waveform with the oscilloscope and note whether or not distorted at the following points: There should be a clean sine wave at all points.

      I. Acceleration jack on Dial-A-Gain.
      II. Amplifier output jack on console.
      III. Input signal to amplifier from oscillator. To obtain this it is necessary to use clip leads inside the console or amplifier at the input.
      IV. This check is usually sufficient to isolate the part of the system causing trouble. Sometimes it is necessary to use an ungrounded power line plug on the scope to eliminate ground loops.

   g. If the system has a multichannel Dial-A-Gain such as the Model 603 or 604, try changing to the other channels. In four channel units, make the change from channels 1 or 2 to channels 3 and 4 as there are two channels per power supply. This will eliminate power supply problems.

   h. Many times if there is an electrical malfunction, it will cause the shaker to rattle or sound like it is falling apart. These sounds are due to the shaker table trying to follow an erratic electrical input. Before assuming from the sounds that the shaker has fallen apart, the check above listed f-II should be performed. If the amplifier output is badly distorted, then the fault is probably electrical, and not mechanical.

TROUBLE SHOOTING THE SYSTEM

4. i. If the signal in check f-I above is erratic, a second accelerometer should be mounted on top of the shaker, and a new cable connected into the Dial-A-Gain. Then repeat check f-I. One of the most frequent causes of trouble is the accelerometer cables, which are quite fragile.

j. If the signal in check f-III above is erratic, another oscillator can be connected to the system. If the system has a BK Automatic Controller, the external oscillator can be plugged into the jack in the upper left side of the front panel, with the Output Switch moved from "linear" to "ext. osc." position.

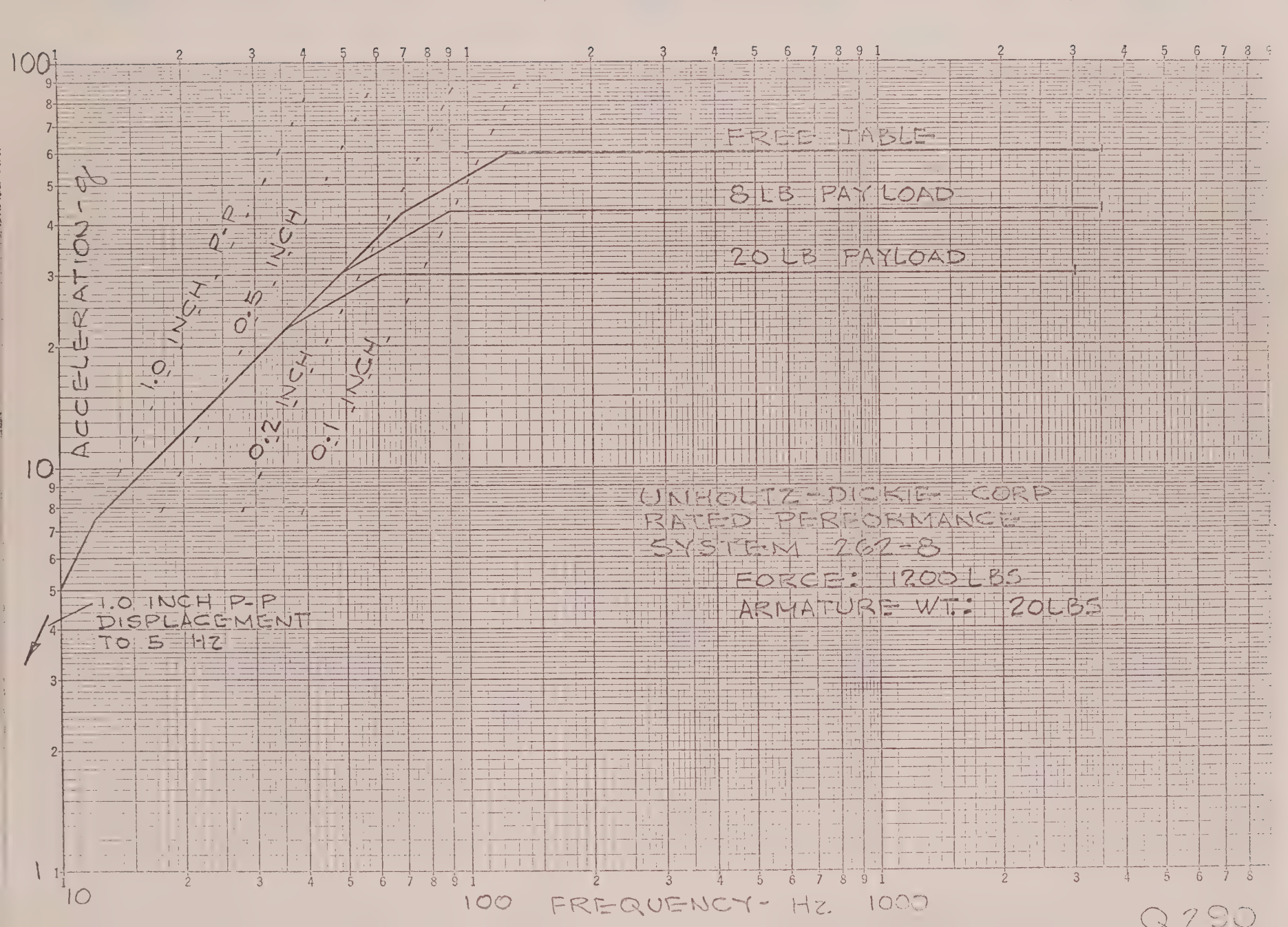
k. Ground loops and 60 cycle pickup can sometimes be cleared up by ungrounding all accelerometers mounted on specimens or fixtures. Also any instruments attached to the system may require the use of ungrounded or "cheater" power line plugs.

l. If the shaker field blows fuses or if the "g" level is well below the level given in check (e) above, then disconnect the shaker power cable and check at the shaker for a resistance to ground on the shaker field coils. Use a VOM for this check.

m. If you call the factory for additional assistance, it is most helpful if some of the above checks have been performed and values recorded where applicable.

To assist in describing the system operation, the following diagrams are included:

Title	Dwg. No.	Chg.
Schematic Wiring, System	D6898-58	A
Customer Information, System	AE599	13
Schematic, Model A102 Power Amplifier	D6878 58	A
BK Automatic Control Schematic	D8003	NC
Instrument Interconnection		
Schematic, Dial-A-Gain Model 601R-A	910403	NC


ACCELERATION - g
FREQUENCY - Hz.
10
100
1000
1.0 INCH P-P
0.5 INCH
0.2 INCH
0.1 INCH
FREE TABLE
8 LB PAYLOAD
20 LB PAYLOAD
1.0 INCH P-P
DISPLACEMENT
TO 5 Hz
UNHOLTZ-DICKIE CORP
RATED PERFORMANCE
SYSTEM 262-8
FORCE: 1200 LBS
ARMATURE WT.: 20 LBS

Q290

UNHOLTZ-DICKIE CORPORATION
2994 WHITNEY AVENUE
HAMDEN, CONNECTICUT 06518
PHONE (203) 288-3358

ACCELEROMETER

OPERATING AND INSTRUCTION MANUAL

GENERAL DESCRIPTION

This accelerometer is a transducer which converts a vibratory acceleration into an electric signal. It consists of a piezoelectric crystal, one side of which is connected to an inertial mass. The other face of the crystal is fastened to the accelerometer base which is mounted at the place where the vibration (or shock) is to be sensed. During acceleration, the inertial mass exerts a force on the crystal which is F = Ma (Force equals mass times acceleration). Two general types of accelerometer construction are shown in Figs. 1 and 2.

The piezoelectric crystal has the property of producing an electrical signal proportional to the amount of mechanical deformation of the crystal. In the case of the accelerometer, this deformation is caused by the inertial force of the mass acting on the crystal face.

The electrical signal put out by the accelerometer can be sensed as either an electrical charge or as an electrical voltage, depending on the type of instrument used to measure the signal. Fig. 3 shows the simplified charge equivalent circuit of an accelerometer connected to a charge amplifier.

Fig. 4 shows the same charge equivalent circuit into a voltage amplifier. Note that in both cases, the charge equivalent circuit is used. A voltage equivalent circuit is also possible, but it is a little less simple to analyze, and the location of the capacitances is more artificial. In the circuits of Figs. 3 and 4, the capacitances of the cable and amplifier inputs are located to correspond with our intuitive understanding of their physical location. For example, cable capacitance is shown from one lead to the other, corresponding to the capacitance that exists between the center conductor and the shield of a cable.

SENSITIVITY

A. Voltage Sensitivity

The charge equivalent circuit also leads to the simplest calculation of voltage sensitivity for any load capacitances.

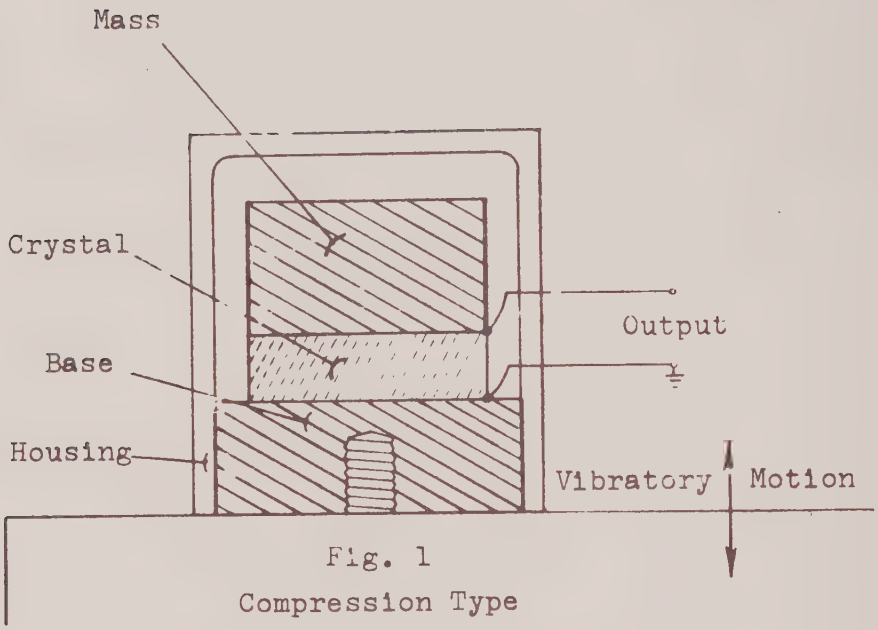


Fig. 1
Compression Type

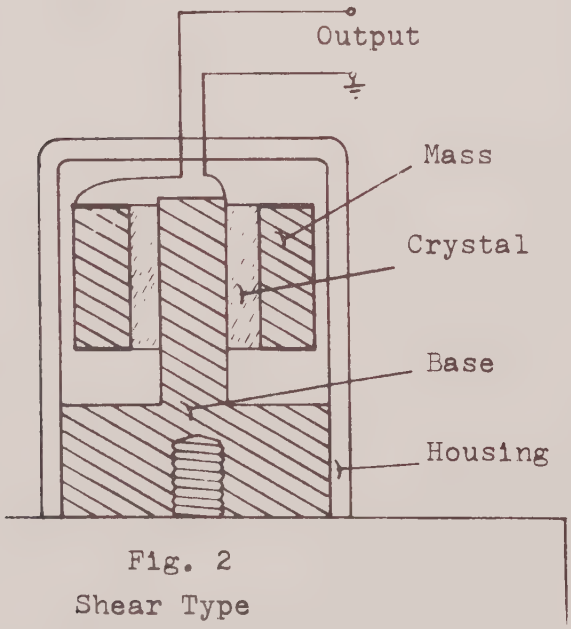


Fig. 2
Shear Type

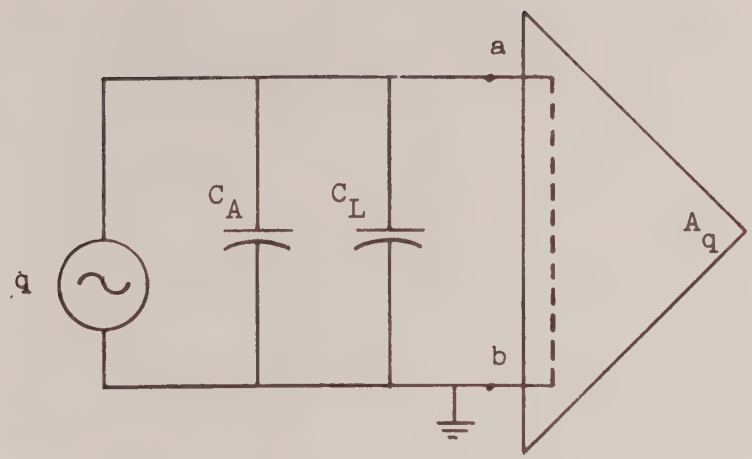


Fig. 3: Charge Equivalent Circuit into a Charge Amplifier

V_{ab} = 0 Because of Virtual Gnd in Charge Amp

C_A = Accelerometer Internal Capacity
C_L = Total Load Capacity (Cables & Amplifier)
A_Q = Charge Amplification
A_V = Voltage Amplification

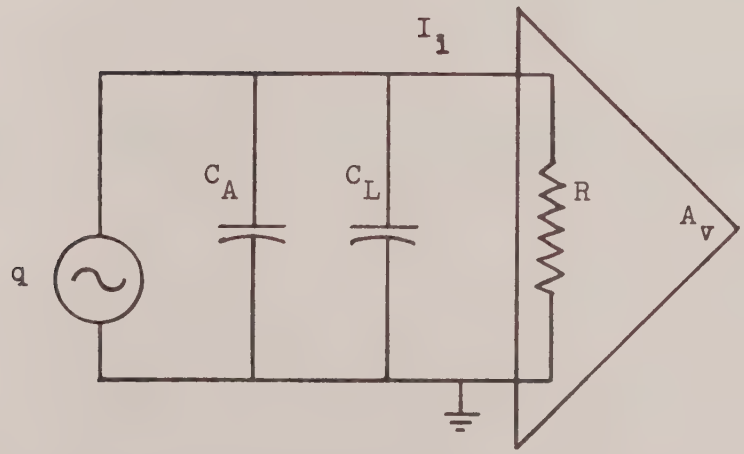


Fig. 4: Charge Equivalent Circuit into a Voltage Amplifier

I_i = 0 because of large input Resistance R

The loaded sensitivity, S_L is simply the charge sensitivity, Q divided by the sum of all the capacitances.

$S_L = \frac{Q}{C_{Accel} + C_{cable} + C_{input}}$ written also as $S_L = \frac{Q}{C_A + C_L}$

1st Example:

Given the Model 25D21 Accelerometer with a charge sensitivity of 33 pk pcmb/g pk and an internal capacitance of 1500 pf., (both at 100 Hz) determine the voltage sensitivity to be dialed on a Model 608 Amplifier in the voltage mode, with 10 pf input cap. and a 10 ft. cable which has 305 pf cap. Note that the Model 608 requires peak mv per peak g.

Answer:

$$S_L = \frac{Q}{C_A + C_L} = \frac{33 \times 10^{-12}}{(1500 + 305 + 10) \times 10^{-12}}$$

$S_L = 18.2$ pk mv/g pk

A second formula can also be used for calculating the voltage sensitivity:

$$S_L = S_{oc} \frac{C_A}{C_A + C_L}$$

where,

S_{oc} = open circuit sensitivity in rm rms/g peak

2nd Example:

With the same 25D21 Accelerometer, determine the RMS voltage sensitivity to be set on the dial of a Model 601 Dial-A-Gain

$$S_L = \frac{Q}{C_A + C_L} \times .707$$

$S_L = 12.9$ rms mv/g peak

3rd Example:

With the same 25D21 Accelerometer, determine the RMS voltage sensitivity using the second formula:

$$S_L = S_{oc} \frac{C_A}{C_A + C_L}$$

$$S_L = 15.6 \frac{1500}{1500 + 305 + 10}$$

$$S_L = 12.9 \text{ rms mv/g pk}$$

Where $S_{oc} = \frac{Q}{C_A} \times .707 = \frac{33 \times 10^{-12}}{1500 \times 10^{-12}} \times .707 = 15.6$

Fig. 5 expresses equation 1 in nomograph form. To use this nomograph to obtain the loaded voltage sensitivity S_L, lay a straight edge between the given charge sensitivity on the right hand column, and on the total capacitance, including the cable, accelerometer and amplifier capacitance, on the left hand column. Read the S_L in the center column in mv peak per g peak. Multiply this answer by .707 if the mv rms per g peak is desired.

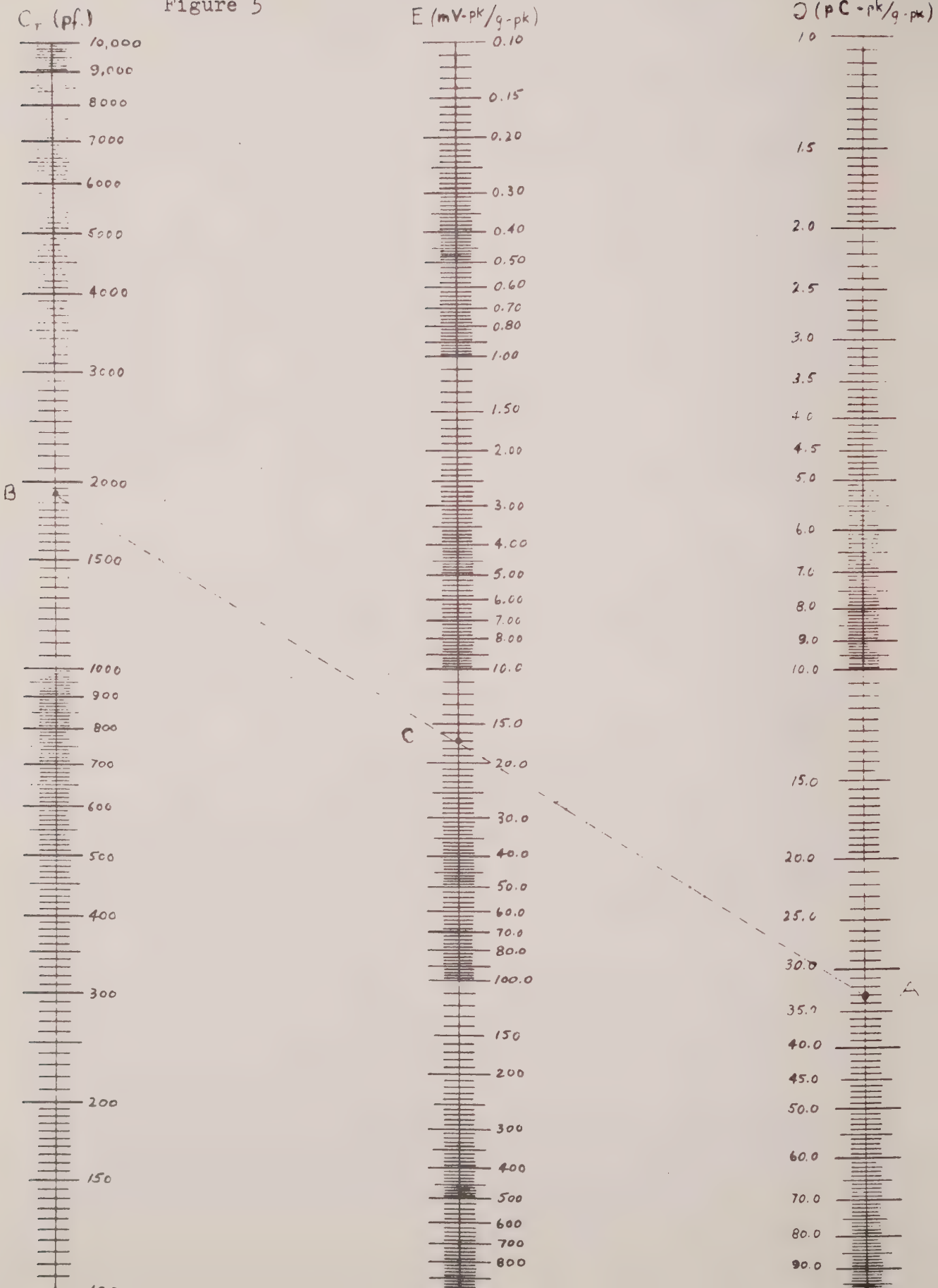
4th Example:

To use the nomograph for finding the same 25D21 Accelerometer loaded sensitivity, lay the right hand end of a ruler on point A on Fig. 5, the given charge sensitivity. Lay the left hand side of the ruler on point B, the sum of all the capacitances. Read the answer at point C.

B. Charge Sensitivity

With a charge amplifier, the charge sensitivity of the accelerometer is independent of the cable capacitances or other loading capacitances. Simply dial the given charge sensitivity into the amplifier, being careful to distinguish between rms or peak sensitivities.

Figure 5


C_T (pf.)
10,000
9,000
8000
7000
6000
5000
4000
3000
2000
1500
1000
900
800
700
600
500
400
300
200
150
B
E (mV-pk/g-pk)
0.10
0.15
0.20
0.30
0.40
0.50
0.60
0.70
0.80
1.00
1.50
2.00
3.00
4.00
5.00
6.00
7.00
8.00
10.0
15.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
100.0
150
200
300
400
500
600
700
800
C
Q (pC-pk/g-pk)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
6.0
7.0
8.0
9.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
60.0
70.0
80.0
90.0
A

ACCELEROMETER CHARACTERISTICS

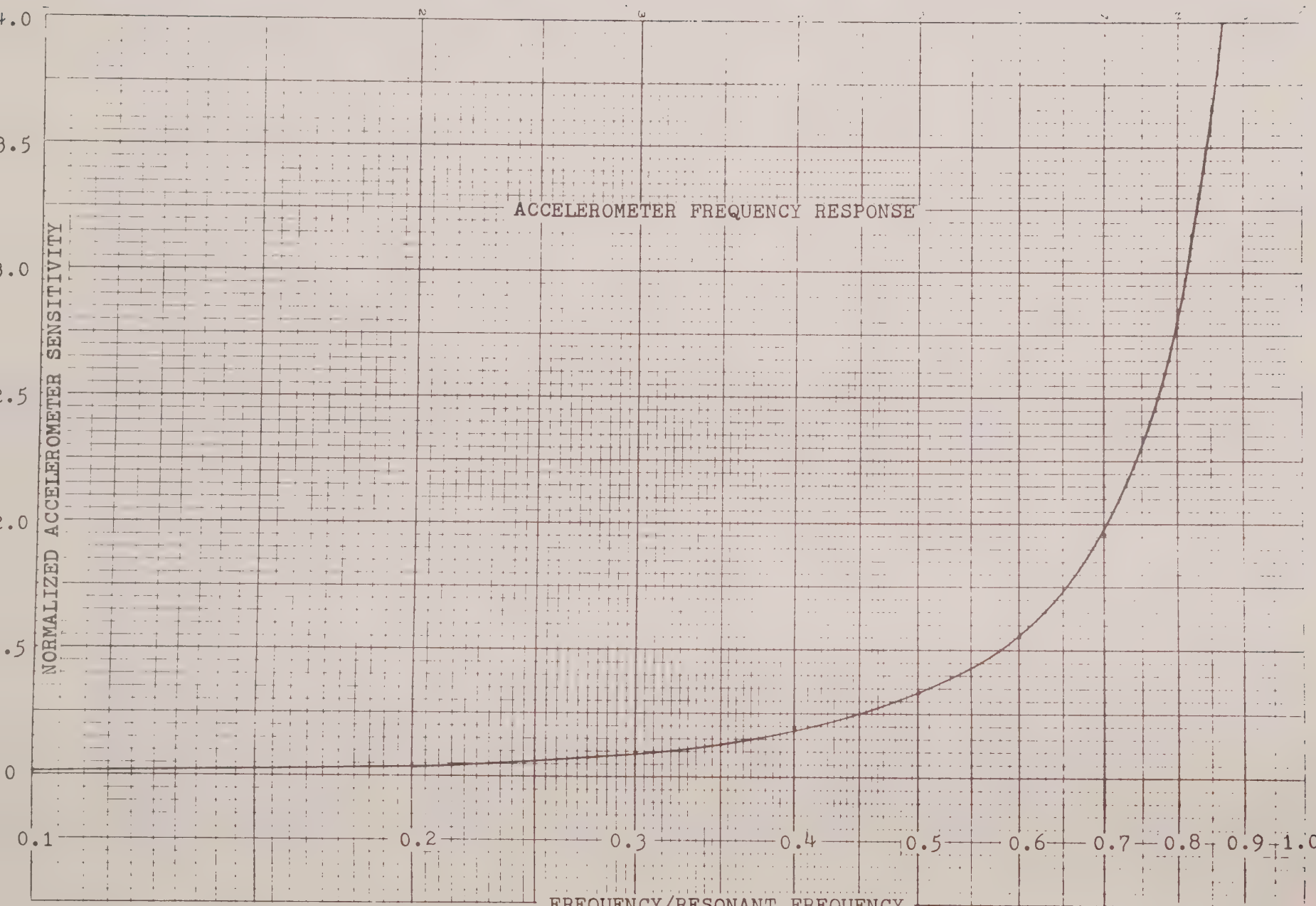
1.0 General

In considering the accuracy of measurements with an accelerometer, a number of factors should be taken into account. For a given accelerometer, variations in sensitivity within specified limits occur over a frequency range, a temperature range, and over a dynamic range. In addition, cross axis sensitivity, case and base thermal shock or mechanical strain sensitivity, and cable whip sensitivity, all can affect measurements. Fortunately, in a modern, well designed accelerometer, many of these effects are negligible. These accelerometer characteristics can be varied by the choice of piezoelectric material and by the mechanical design utilized, resulting in the various models offered.

1.1 Frequency Response

A typical accelerometer has approximately flat sensitivity versus frequency in the usable band from a few cycles a second to thousands of cycles per second. At the upper end of this frequency band, the sensitivity of the accelerometer starts to increase. The spring mass resonance of the accelerometer which occurs at a much higher frequency, results in an increased output for a given input. Fig. 6 shows this rising response on a normalized frequency basis for an undamped resonant system. From the curve, it is seen that at approximately 1/5 the natural frequency (.2 on the normalized scale), the response is up about 4%. This point is usually taken as the useful upper frequency limit of the accelerometer. For example, the Model 25D41 has a resonant frequency at about 30,000 Hz. In its published specifications, the useful upper frequency limit is given as 6,000 Hz, which is 1/5 of 30,000 Hz. Above this 6,000 Hz, the sensitivity is above 4% and rising with increasing frequency. For making measurements above 6,000 Hz, an accelerometer with a much higher resonant frequency should be used. a higher natural frequency is usually achieved by making the accelerometer smaller, and for a trade-off of lower sensitivity.

NO. 340 L110 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
1 CYCLE X 10 DIVISIONS PER INCH



It should be noted that the accelerometer resonant frequency mentioned above is a mounted resonant frequency. This is the lowest resonant frequency obtained and is measured with the accelerometer attached to a relatively very heavy mass, approaching an infinite mass.

The lower limit of the useful frequency range of an accelerometer is different when used with a voltage amplifier than with a charge amplifier.

When used with a charge amplifier, the low frequency limit is usually only that of the charge amplifier alone. This is usually about 2 to 5 cycles, or lower. Below these frequencies the amplifier output is no longer flat, and the combined accelerometer amplifier response is usually down.

With a voltage amplifier, the low frequency limit may be either the amplifier low frequency response, or the result of the time constant of the combined RC circuit, where R is the amplifier input resistance, and C is the accelerometer and cable capacitance. Fig. 7 is a normalized curve of this low frequency drop-off. As an example, the capacitance of a 25D21 is 1300 pf and a 300 pf cable is connected to a voltage amplifier with a 400 megohm input resistance. Find the frequency at which the sensitivity is down 5%. From Fig. 7 the 5% point is nearly fRC = ~~.30~~ .37. Then:

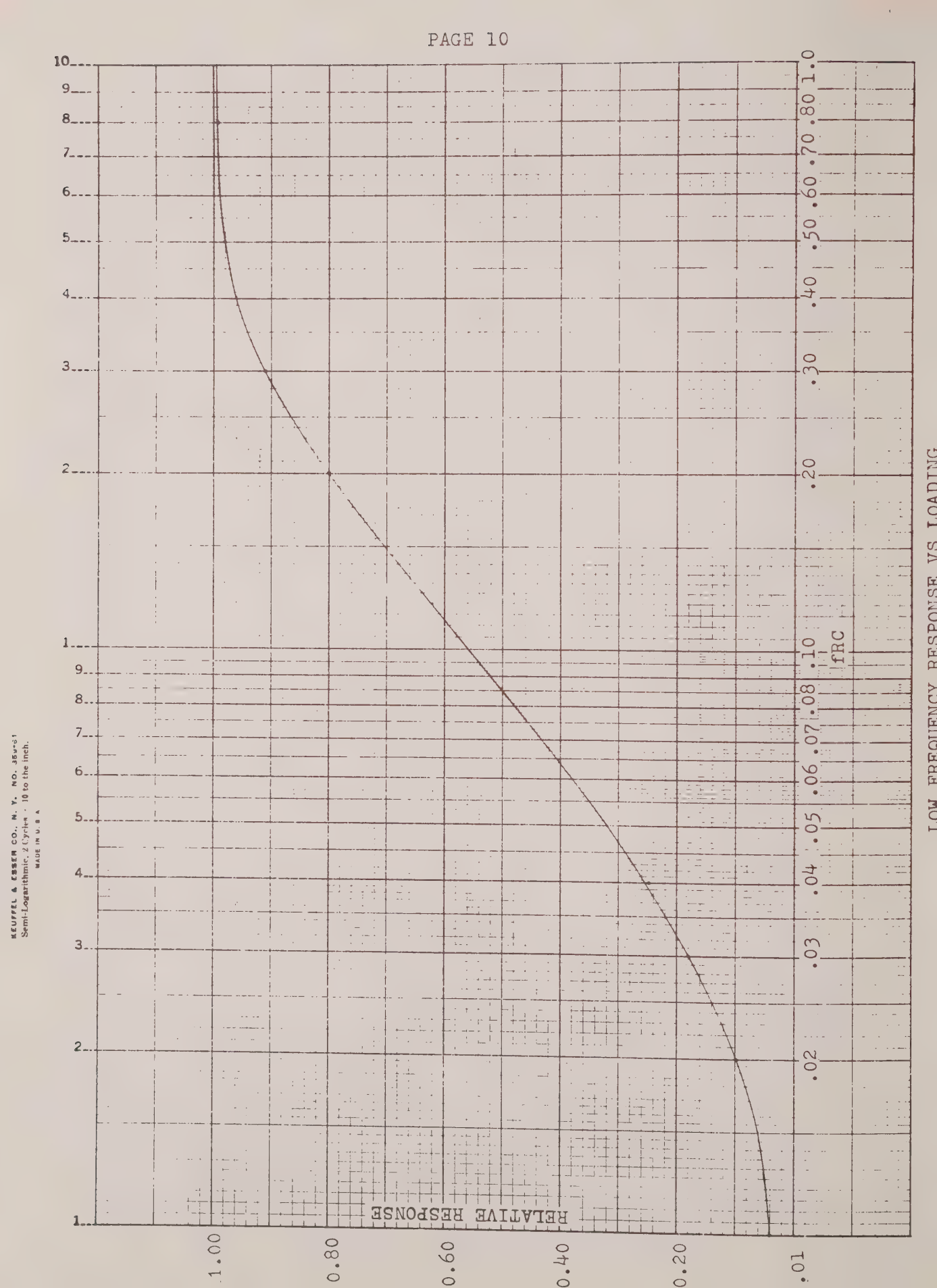
$$f \times 4.00 \times 10^{8} \times 16.00 \times 10^{-10} = .37$$

$$f = \frac{.37}{64 \times 10^{-2}} = \frac{37}{64} \text{ Hz} = .58 \text{ Hz}$$

Since the amplifier low frequency response is probably not this low, it alone would determine the low frequency limit.

1.2 Sensitivity Variations with Temperature (Note: This section will vary depending on which accelerometer is used.

1.2.1 Voltage Type Accelerometers - The Unholtz-Dickie Models D and E type accelerometers utilize a Clevite PZT type ceramic element chosen for highest sensitivity and temperature stability when operating into voltage amplifiers. They have higher variation in sensitivity versus


RELATIVE RESPONSE
1.00
0.80
0.60
0.40
0.20
.01
fRC
LOW FREQUENCY RESPONSE VS LOADING
KEUFFEL & ESSER CO., N. Y. NO. 359-51
Semi-Logarithmic, 2 Cycles · 10 to the inch.
MADE IN U. S. A.

temperature when used in the charge mode. If wide temperature ranges are encountered, and charge amplifier use is dictated, another model accelerometer utilizing a different crystal material should be chosen. Refer to the discussion elsewhere on crystal materials.

Fig. 8 shows the sensitivity variations over the ranges of temperatures for Models E and D accelerometers. (Models 2E5, 5D21, 25D21 etc.)

Note that the load (cable) capacitance can be chosen to optimize the sensitivity over a particular temperature range. The curves show that for room temperature operation, the best cable length to use is a cable with about half the capacitance of the accelerometer capacitance. Typical coaxial cable capacitance runs about 29 to 30 pf capacitance per foot.

When operated into charge amplifiers, the cable capacitance does not have any effect on the sensitivity variations with frequency. In general, for the D and E models, the charge sensitivity will vary $\pm$ 5% when the temperature ranges from 0°F. to 165°F.

1.3 Accelerometer Linearity - Sensitivity Variations with Dynamic Range

Most piezoelectric accelerometers are extremely linear over a very wide range of g levels. A dynamic range of 80 to 100 db or more with less than 1% error is quite common. In fact, it is quite difficult to measure the linearity error in an accelerometer, it is so small.

1.4 Cross Axis Sensitivity

An unwanted output from an accelerometer, perpendicular to the normal axis of vibration is referred to as cross axis sensitivity or cross talk. Good accelerometer design can keep it below 3% or less. The cross sensitivity has a maximum value in a certain direction, with a minimum value in a direction 90° away. A typical plot of the cross axis motion is shown in Fig. 9.

K&E 10 X 10 TO THE INCH 46 0703
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO

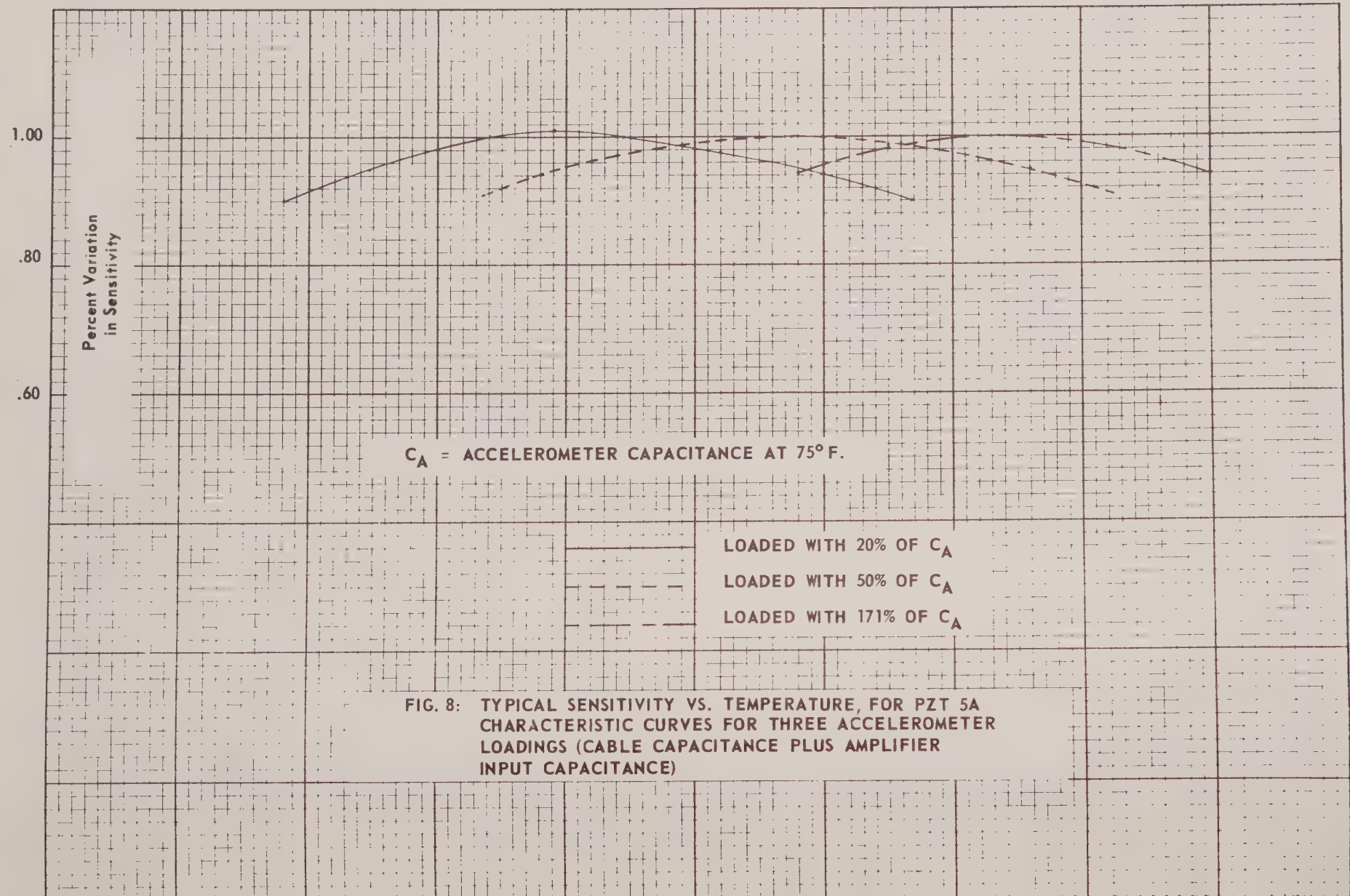


FIG. 8: TYPICAL SENSITIVITY VS. TEMPERATURE, FOR PZT 5A CHARACTERISTIC CURVES FOR THREE ACCELEROMETER LOADINGS (CABLE CAPACITANCE PLUS AMPLIFIER INPUT CAPACITANCE)

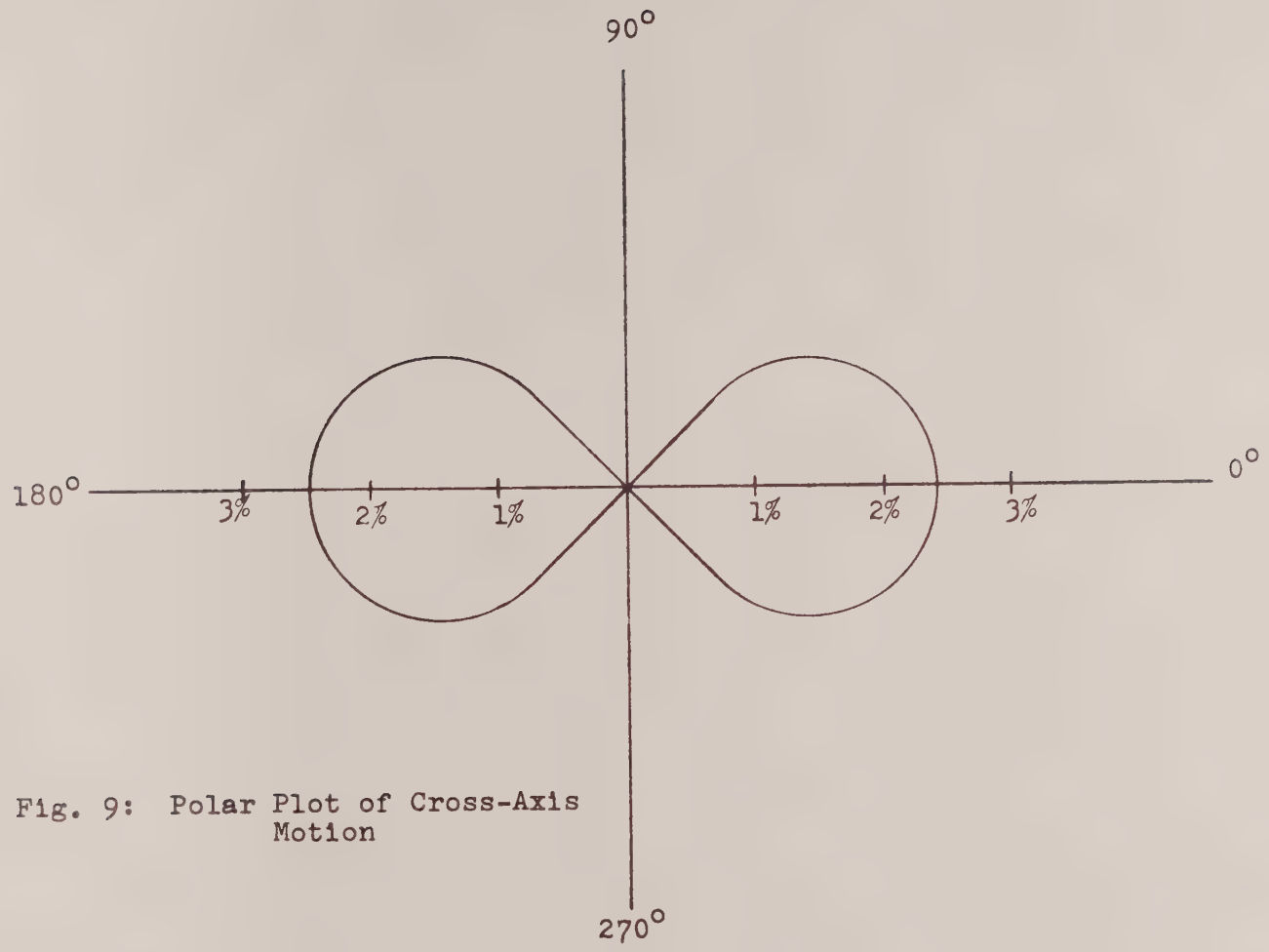


Fig. 9: Polar Plot of Cross-Axis Motion

The cross axis sensitivity is measured at a single frequency, below 200 Hz. The assumption is then made that this cross sensitivity remains essentially unchanged over the frequency range up to at least a few thousand cycles. Actual measurement of this frequency response of cross axis motion leads to many uncertainties. However, many measurements of shaker cross axis motion up to 10,000 Hz with various shear type accelerometers lead us to believe that there are no major variations in cross axis sensitivity. For further information on this subject, refer to reference 1 in the attached list of references, Appendix II.

1.5 Case and Base Strain Sensitivity, Thermal Shock Sensitivity, Cable Whip Sensitivity

In a poorly designed accelerometer, where the crystal and mass are not sufficiently isolated from the accelerometer exterior housing, quite sizeable outputs can result from causes unrelated to axial vibrations. In every case, these unwanted outputs are caused by strains in the outer housing which strain the crystal, either directly or through the seismic mass. Fig. 10 shows a typical poorly designed accelerometer. The case provides the spring loading of the mass on the crystal. It is obvious that if the case is strained in some manner to change its height, the compression loading of the mass on the crystal will change, and an output will result.

One of the simplest methods of checking an accelerometer for this case sensitivity is to apply a thermal shock. An incandescent light bulb is placed a few inches away from the side of the accelerometer. When the light bulb is turned on, the accelerometer output can be observed on a meter or a scope. in a well-designed accelerometer, the output from such a thermal shock is negligible. In poorly designed accelerometers, even the temperature changes resulting from air drafts in a normal room can give outputs of several "g's".

Another check for case sensitivity is the effect of cable whip. If the cable connector on the accelerometer has varying forces on it, these forces are transferred to the case, causing minute strains in the case. Again, in a good accelerometer

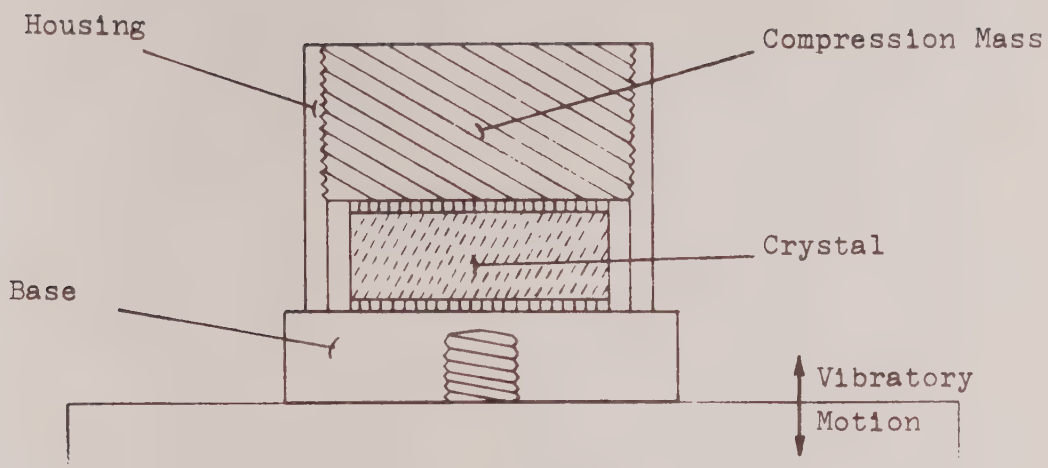


Fig. 10: Poor Accelerometer Design
Stress on housing leads
to unwanted output.

design, such strains resulting from cable whipping should not result in an output signal. To check this, simply flex the accelerometer cable rapidly close to the connector, with the accelerometer mounted on a large rigid structure. Any output from this cable flexing can be noted on a meter or scope.

Base strain sensitivity is similar to the case sensitivity described above. Many times the surface of the test structure to which the accelerometer is attached is bending as well as vibrating. If this bending causes strains in the accelerometer base such that an output results, the accelerometer is said to be base strain sensitive.

Base strain sensitivity is checked by mounting the accelerometer at the inboard end of a cantilever beam, as in Fig. 11. When the free end of the beam is vibrated a known amount, a known strain is applied to the base of the accelerometer, with however negligibly small accelerations, if the frequency is very low, typically 5 Hz.

In the accelerometer design of Fig. 1, page 2, base strain sensitivity can be a problem, whereas in the shear type of Fig. 2, straining the base does not result in an output. The compression design of Fig. 1 can be made relatively free of base strain problems by special compromises, such as making the base very thick relative to the diameter to minimize strain, or to build a double base which will not transmit the strains.

gid beam
mounting

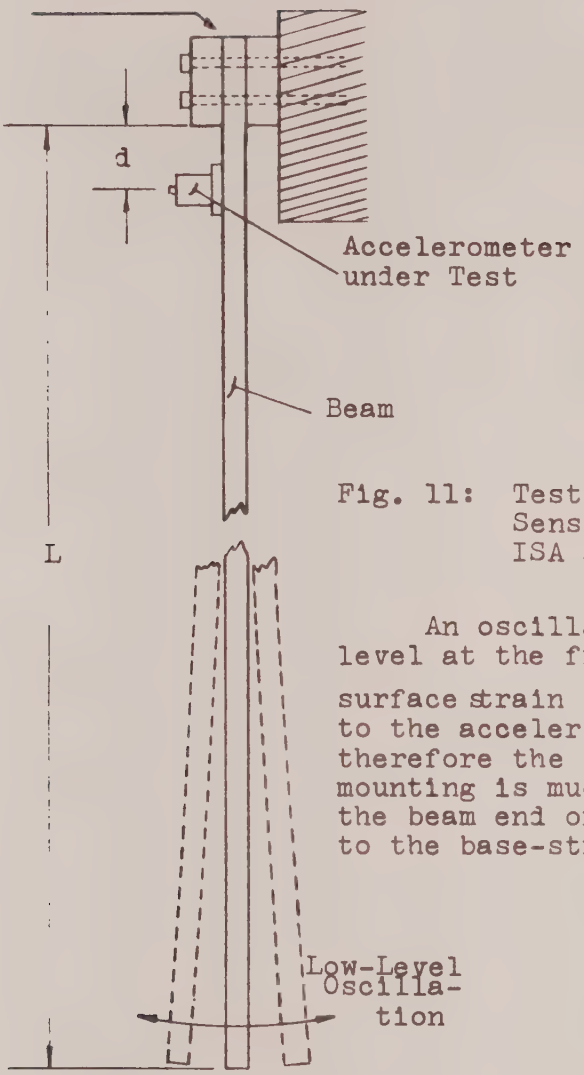


Fig. 11: Test Method for Base-Strain Sensitivity: Adopted from the ISA Standard RP 37.2, para. 6.6

An oscillatory displacement at a low g-level at the free end of the beam produces a surface strain on the beam which is transmitted to the accelerometer base. Since L d, and therefore the oscillation at the accelerometer mounting is much less than the oscillation at the beam end only the accelerometer output due to the base-strain will be significant.

Piezoelectric Materials

The heart of the accelerometer is the crystal, which puts out the signal proportional to strain. There are only a few materials of the many that exhibit piezoelectricity that find use in accelerometer designs. The following is a partial list, with the chief characteristics or reasons for their use:

Material	Usable Upper Temp. Limit	Strain Coefficient (compression design)	
Quartz (SiO_2)	500°-600°F.	2.3	Most stable material, flattest freq.& temp. response, however rather low output.
Barium Titanate ($BaTiO_3$)	120°C. curie	150	Historically, the first of the ceramics used. In most cases has been replaced by Lead Zirconate Titanates
Lead Zirconate Titanate $Pb(Zr,Ti)O_3$	360°C. curie	320	Currently the most widely used ceramic. Performs best in voltag mode, with quite high signal output
Lead Metaniobate ($PbNb_2O_6$)	570°C curie	85	For special application Has a very low Q.
Bismuth Strontium Titanates	750°F. and higher	17	For charge and voltages combined in one accel-erometer. Quite flat response over wide rang of temperature. A more recent crystal material which is a good compron between quartz and Lead Zirconate Titanate.
Lithium Gallium Oxide ($LiGaO_2$)	(curie point about 1250°C.	7.7	About twice the output of quartz, this new crystal shows promise for high temperature applications.
Lithium Niobate ($LiNbO_3$)	-	-	Also a new, high tem-perature material

Instrumentation - Accelerometer Amplifiers

1. General Discussion

Accelerometers may be operated into two types of signal-conditioning devices - voltage amplifiers and charge amplifiers. Historically, voltage amplifiers preceded charge amplifiers - and thus many older types of accelerometers are designed for optimal performance with a voltage amplifier. However, these older types may still be used with a charge amplifier under more restricted temperature conditions. Other accelerometers are designed for optimal use with charge amplifiers, and yield a flat response with variations in frequency and temperature.

The question of whether to use a voltage or a charge instrument depends mainly on the environmental test conditions encountered by the researcher. The basic advantages of a voltage instrument are (1) lower cost and (2) less circuitry. The advantages of a charge instrument are (1) the charge amplifier allows the use of very long accelerometer cables - up to 1 mile - and (2) calibration setting per accelerometer is sufficient - regardless of cable length and cable capacitance. With a voltage amplifier, three items must be handled: (1) voltage sensitivity, (2) accelerometer capacitance, and (3) cable capacitance. With a charge amplifier, only the charge sensitivity is necessary.

With modern accelerometers having large accelerometer capacity and voltage sensitivity, voltage instruments may be used with moderately long cable lengths. The main problem is that since voltage sensitivity drops with an increase in cable capacitance for a given accelerometer, care must be taken that the signal-to-noise ratio does not become too large when cable length is increased.

These modern high-capacity accelerometers may also be used directly into a VTVM or an oscilloscope, providing the input resistance of the instrument is high enough to provide good low-frequency response. For example, the U.D. Model 5D41

accelerometer with C_A = 10,000 pf operated into an instrument with a 10 Megohm input resistance gives a low frequency time constant RC = $(10^4 \times 10^{-12} f)(10^7 \Omega)$ sec = 10^{-1} sec. which provides a low frequency cutoff at 10 Hz

2. Voltage Amplifier Operation:

A voltage amplifier is basically of the cathode-follower type, with a high resistive input impedance which ranges from several hundred to several thousand meghoms in typical cases. Vibrating the accelerometer results in the production of a charge proportional to the acceleration which appears as a voltage across the accelerometer capacitance C_A and the cable capacitance C_c according to the equation

$$E = \frac{Q}{(C_A + C_c)}$$

This shows the dependence of the input voltage on the circuit capacitance when a voltage amplifier is used). The low-frequency response of the voltage amplifier is determined by the time constant $R(C_A+C_c)$ where R is the input resistance to the amplifier. The higher the input resistance R, the higher the time constant; therefore the low-frequency cutoff is decreased with an increase in R.

3. Charge Amplifier Operation:

The charge amplifier is a special type of operational amplifier with a relatively large capacitor in the feedback path: See figure 12.

The amplification factor A is very large and negative, and the input impedance to A is very large. We consider this amplifier with a charge-equivalent accelerometer source: (See Fig. 13)

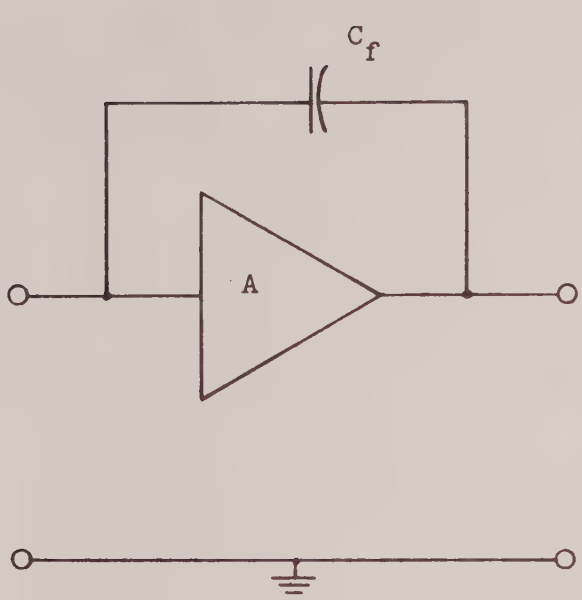


Fig. 12

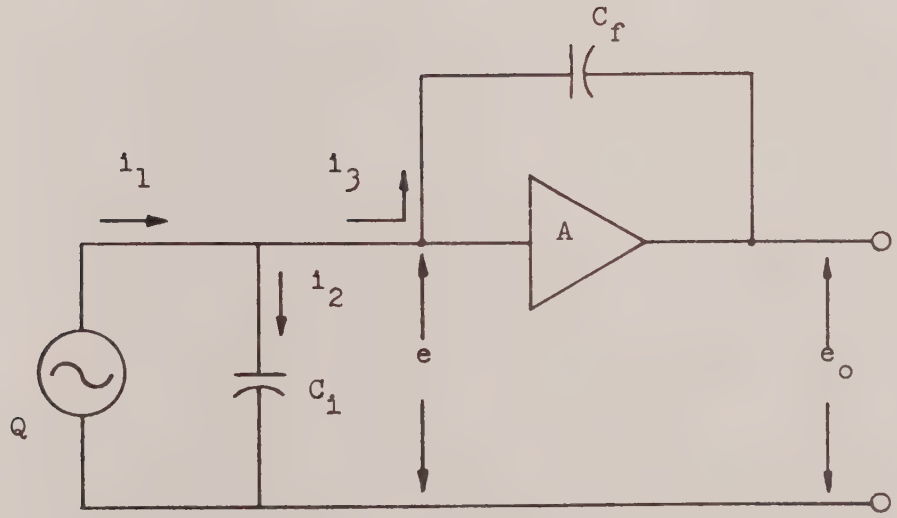


Fig. 13

$i_1 = i_2 + i_3$ (since input Z to A is very large)

$Q = C_i e + C_f(e - e_o)$

$Q = \frac{C_i e_o}{A} + \frac{C_f e_o}{A} - C_f e_o$ (since $e_o = Ae$)

$\frac{Q}{e_o} = \frac{C_i + C_f}{A} - C_f$

If the quantity $\frac{C_i + C_f}{A}$ is negligible in comparison with C_f; that is, if the gain A is very large, $\frac{Q}{e_o} \cong -C_f$, or

$$e_o \cong -\frac{Q}{C_f}$$

In other words, the output voltage depends only on the charge input and not on the value of C_i.

The assumption was made that

$$\frac{C_i + C_f}{A} \ll C_f$$

Let us see what variation of C_i would produce a 1% error, from the above approximation:

Example:

Let $A = 5000$
$C_f = 1000$ pf

$\frac{C_i + C_f}{A} = \frac{C_f}{100}$ (that is, 1% of C_f)

$\frac{C_i}{A} = C_f(\frac{1}{100} - \frac{1}{A}) \therefore C_i = C_f(\frac{A}{100} - 1)$

$$C_i = 1000 \left(\frac{5000}{100} - 1\right)$$

$$C_i = 1000 \ (50 - 1) = \ 49{,}000 \text{ pf}$$

Thus C_i may vary from very small values up to 49,000 pf with a 1% change in output (49,000 pf = 1500' of coax cable).

APPENDIX I

USE OF ACCELEROMETERS FOR SHOCK TESTING

SHOCK TESTING

I. INTRODUCTION

Due to the high acceleration levels encountered in shock testing, and the aperiodic nature of shock pulses with the associated broad frequency spectrum, the accelerometer and signal-conditioning equipment must be selected with care. The prime consideration is that the output of the signal-conditioning equipment be as accurate a reproduction of the acceleration pulse input as possible.

To achieve accurate pulse reproduction, there are two major considerations. First of all, both the accelerometer and signal conditioner must have responses which are linear over a wide range of acceleration amplitudes. This prevents generation of spurious frequency components. Second, the frequency response of both the accelerometer and the signal conditioner must be flat over a wide frequency range. In addition, special attention must be paid to the phase characteristics in order to minimize distortion of the pulse shape by unequal time delays over the frequency band associated with the pulse spectrum.

II. ACCELEROMETER CHARACTERISTICS

The specifications for Unholtz-Dickie accelerometers include the maximum acceleration that may be handled without damage and also the associated amplitude linearity factor. The flatness of the voltage sensitivity with frequency is guaranteed and the resonance frequency is also specified.

The accelerometer responds down to zero frequency. Typical flatness is $\pm$ 5% to approximately 1/5 the resonance frequency, which is typically 30 kHz or above. Due to the low damping associated with accelerometer resonances, the deviation of the phase response from zero degrees is small in the frequency range of interest.

III. SIGNAL CONDITIONER CHARACTERISTICS

The Unholtz-Dickie Model 11 Series Charge Amplifier is well suited for shock instrumentation. The amplitude linearity of the instrument is excellent ($\pm$ 1%), and accelerations up to 10,000 g may be observed using accelerometers having sensitivities from

III. (Continued)

1-10 pC/g. For accelerometers with sensitivities from 0.1 to 1.0 pC/g undistorted accelerations up to 100,000 g may be obtained.

The frequency response of the instrument is flat over a wide frequency range. The response of the standard version is within 5% at 2 Hz, 2% from 5 Hz to 10 kHz, and approximately 3 dB down at 20 kHz. An internal Butterworth filter causes the response of the amplifier to decrease at 18 dB/octave outside the passband. This is necessary to filter any possible ringing at the accelerometer resonance frequency. A special version of the Model 11 has extended low-frequency response for reproducing long pulses.

For shock applications, the phase specifications are more important than amplitude specifications, assuming, of course, that the latter are flat within 2%. This will be shown in the following sections, and the results given are applicable to all signal conditioners. The discussion is logically broken up into two parts, one for the low frequency phase response, and the other for the high frequency phase response. It should be noted at the outset that the phase response of the Model 11 is well controlled at both ends of the spectrum.

IV. LOW FREQUENCY RESPONSE

The discussion involving the low frequency response will be centered around the signal-conditioning amplifier, since the accelerometer responds to zero frequency. It is well known that degradation of the low frequency response of an amplifier causes the phenomenon of droop and undershoot in the output signal when the input is an aperiodic rectangular pulse. This phenomenon is shown in Fig. 1.

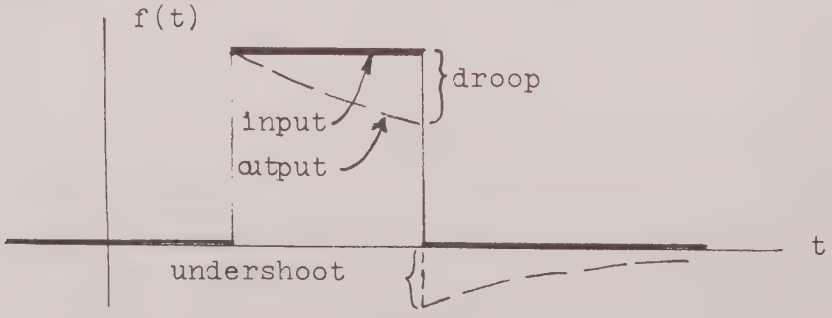


Fig. 1.

IV. (Continued)

Since practically all a.c. amplifiers have more than one pole which affects the low frequency response, it is entirely inadequate to characterize such amplifiers by means of a first-order, low frequency response (one pole). The amplifier analyzed in this section has a number of low frequency poles, which need not be real. It is shown that the distortion characteristics of droop and undershoot can be evaluated or determined accurately by a single phase measurement or specification at a suitable low frequency. Furthermore, a simple method is outlined which allows one to evaluate the error in the output for any specified long pulse applied to the input.

The phasor frequency response of an amplifier may be characterized by Eq(1) which contains as many real poles and pairs of complex poles as necessary. High frequency poles are neglected for the moment. One of the real poles may be associated with the accelerometer cable capacitance and input resistance for voltage amplifiers.

$$H(j\omega) = \frac{V(j\omega)}{G(j\omega)} = \frac{(j\omega)^N}{(j\omega + \omega_1)((j\omega)^2 + 2\zeta_2 \omega_2 j\omega + \omega_2^2)(j\omega + \omega_3)\cdots} \quad (1)$$

(denominator order is N)

(1)

It has been shown that the response of the amplifier in Eq(1) to a unit step function input for reasonably short periods of time is given by

$$v(t) \cong u(t)\left[1 - Kt\right] \qquad \begin{matrix} (\ g(t) = u(t)\ ) \\ (Kt \ll 1) \end{matrix} \qquad (2)$$

where u(t) is the unit step function, and the factor K is given by

$$K = \omega_1 + 2\zeta\omega_2 + \omega_3 \ldots = -\sum^{N} \mathrm{Re}\left\{\text{low freq. poles}\right\} \qquad (3)$$

(1) Valley and Wallman, Vacuum Tube Amplifiers pp 71-89, McGraw Hill Book Co., 1948

IV. (Continued)

We also note that the phase angle of $H(j\omega)$ at low frequencies is given exactly by

$$\theta = \arg\left\{H(j\omega)\right\} = \arctan\frac{\omega_1}{\omega} + \arctan\frac{2\zeta_2\omega_2\omega}{\omega^2-\omega_2^2} + \arctan\frac{\omega_3}{\omega}+\ldots \quad (4)$$

For reasonably small values of θ,

$$\omega >> \omega_1, \omega_2, \omega_3, \ldots \quad (5)$$

and the arctan functions in (4) may be replaced by their arguments[2]

$$\theta \cong \frac{\omega_1}{\omega} + \frac{2\zeta_2\omega_2}{\omega} + \frac{\omega_3}{\omega} + \ldots\ldots \text{(radians)} \quad (5)$$

Multiplying both sides of Eq (5) by W, we see the following important general relation:

$$\omega\theta \cong \omega_1 + 2\zeta_2\omega_2 + \omega_3 + \ldots = K \quad (6)$$

$$(\theta << 1 \quad \text{or} \quad \omega >> \omega_1, \omega_2, \ldots.)$$

The implication of Eq (6) is straightforward. The measurement or specification of θ at a given frequency determines the response of the amplifier to a step function response. The accuracy of Eq (6) and Eq (2) is extremely good as long as the inequalities $Kt << 1$ and $\theta << 1$ are observed. The frequency of measurement is not critical, since $\omega\theta$ is a constant as long as θ is reasonably less than unity (57.3°). For measurement purposes a number of values of θ may be taken and the average value of the product $\omega\theta$ used for the analysis.

Measurements taken directly from the Lissajous pattern in Fig. 2 can be used to determine θ without resorting to conversion to degrees. For charge amplifiers, the test signal is inserted through a series capacitor.

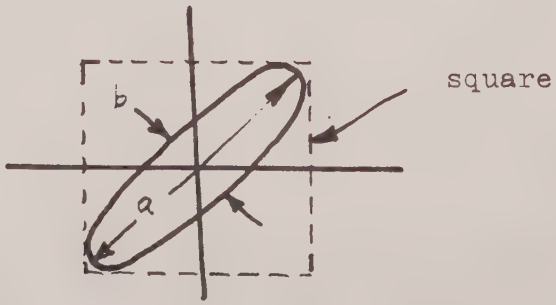


Fig. 2 Low Frequency Lissajous Pattern

(2) Bower and Schultheiss, Intro. to the Design of Servomechanisms, pp. 83-88, John Wiley and Sons, 1958

IV. (Continued)

From Fig. 2

$$\tan^{-1} \frac{1}{2} \theta = \frac{\text{minor axis}}{\text{major axis}} = \frac{b}{a} \tag{7}$$

For small θ,

$$\theta \cong 2 \frac{b}{a} \tag{8}$$

It is easy to see that the constant K cannot be described by a single parameter associated with a first-order system, and not by an amplitude response parameter since there may be complex poles which are used to optimize the flatness of the low-frequency response.

Finally, the response of the amplifier to a general pulse depicted in Fig. 3 may be determined from network theory and Eq. (2). The pulse need not always be unidirectional.

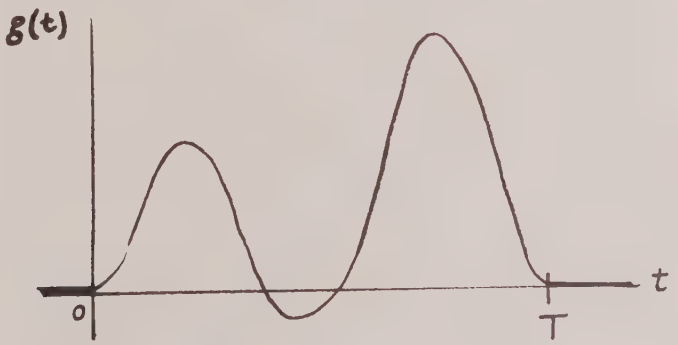


Fig. 3 General Shock Pulse

The weighting function [3], h(t), for the amplifier is useful in determining response to general inputs. The weighting function is the response to a unit delta function input, and is the first derivative of Eq. (2), since the unit delta function is the first derivative of the unit step function. Thus,

$$h(t) \cong \delta(t) - K u(t) \tag{9}$$

(3) Bower and Schultheiss, op.cit., pp 48-50

IV. (Continued)

The output v(t) to a general input, g(t), is given by the convolution integral

$$v(t) = \int_0^t h(t-\tau)\, g(\tau)\, d\tau$$

$$\cong \int_0^t \left[\delta(t-\tau) - K u(t-\tau)\right] g(\tau)\, d\tau \qquad (10)$$

The components of Eq(10) are shown in Fig. 4

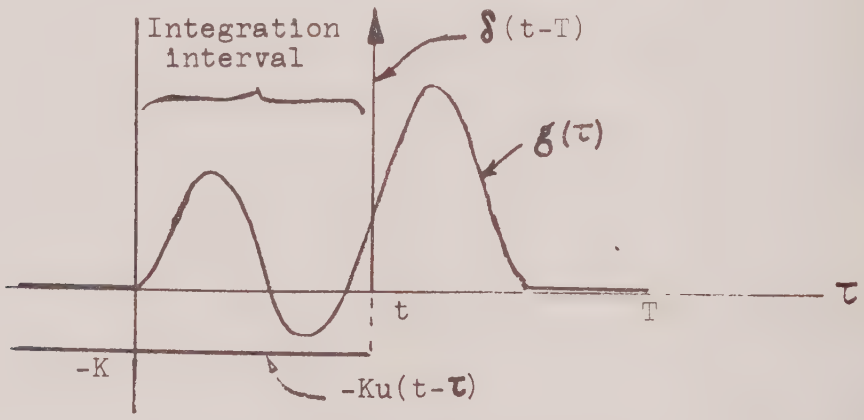


Fig. 4 Components of Convolution Integral

Equation (1)) easily reduces to

$$v(t) \cong g(t) - K \int_0^t g(\tau)\, d\tau \qquad (KT < 1) \quad (11)$$

It is assumed for simplicity that the amplifier gain in the pass-band is unity. In Eq (11), g(t) represents the desired value of the output and the second term represents the error as a function of time. It is interesting to see that the error is related to the integral of the pulse input and the constant $K = \omega\theta$. Eq. 11 can be used with any shape pulse to determine the error at any time. In particular for t = T

$$K \int_0^T g(\tau)\, d\tau \quad = \quad \text{"Undershoot"}$$

IV. (Continued)

The results of Eq.(11) are listed in Table 1 for rectangular, half-sine, and triangular pulses of unit amplitude and duration T. The pulses are shown in Fig. 5, as well as general response shapes.

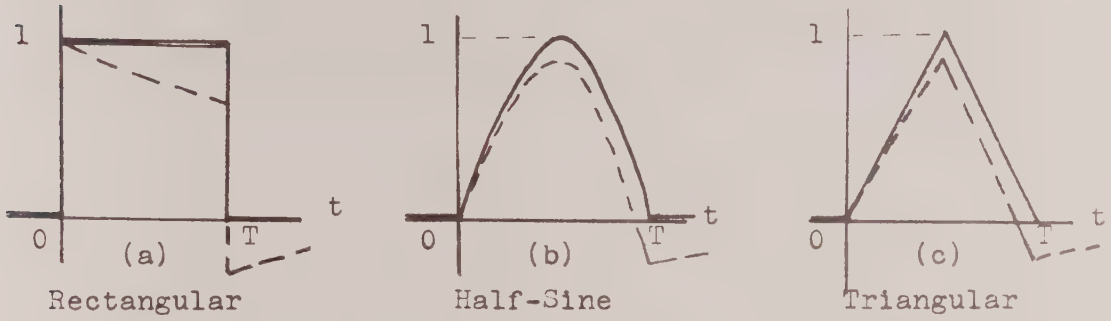


Fig. 5. Pulse Shapes & Responses

KT 1	Rectangular	Half-Sine	Triangular
Error Expression $0 \leq t \leq T$	$-Kt$	$-K\frac{T}{\pi}\left[1-\cos\frac{\pi t}{T}\right]$	$-\frac{K}{T}t^2 \quad \left(0 \leq t \leq \frac{T}{2}\right)$ $-\frac{K}{T}\left[t^2-2\left(t-\frac{T}{2}\right)^2\right] \quad \left(\frac{T}{2} \leq t \leq T\right)$
Undershoot t = T	$+KT$	$+\frac{2}{\pi}KT$	$+\frac{KT}{2}$
Droop (t specified)	$KT \quad (t=T)$	$\frac{1}{\pi}KT \quad (t=\frac{T}{2})$	$\frac{KT}{4} \quad (t=\frac{T}{2})$

Table 1.
Error, Droop, and Undershoot for Certain Shock Pulses

The previous method of analysis, and also Reference (1) suggest a method for compensating for the droop in the pulse response function. If the amplifier has low frequency zeros as well as poles, the expression for K becomes:

$$K = -\sum \mathrm{Re}\{\text{low freq. poles}\} + \sum \mathrm{Re}\{\text{low frequency zeros}\} \quad (12)$$

The insertion of a single low frequency zero such that

$$-\text{low freq. zero} = \omega_L = -\sum \mathrm{Re}\{\text{low freq. poles}\} \quad (13)$$

causes K to be zero, and the initial slope of the step function response to be zero. For this condition, the measured phase

IV. (Continued)
angle for sinusoidal response is such that $\omega\theta \cong 0$ for $\omega > \omega_L$.

Obviously, compensation can never be quite complete since Eq. (2) neglects higher order terms involving t^2, t^3, etc. and the coefficients of these terms are not zero. It is, of course, possible to overcompensate so that the response rises initially.

The Model 11 lends itself very easily to the insertion of a low-frequency zero in the response characteristics. A front panel switch can be used to switch the low-frequency compensation in and out. At the servo (10 mv/g) output of the Model 11, Table 2 gives pertinent performance parameters. For two different pulse widths:

Low Freq. Comp.	5 Hz θ	Measured Droop	
		40 ms	100 ms
Out	$+11^\circ$	24%	50%
In	0°	1.6%	10%

Table 2
Low Freq. Droop - 10 mv/g Output - Model 11

At the tape or galvanometer outputs of the Model 11, the measured droops are approximately twice the values given in Table 2. The low frequency compensation is slightly different from the value necessary to give the performance data in Table 2.

V. HIGH FREQUENCY RESPONSE

The high frequency response characteristics of an amplifier determine the speed at which the amplifier will respond to sudden changes in the input. The phase characteristics for the high end of the amplifier pass-band are also extremely important in that they determine the waveform distortion due to unequal time delay for different frequency components.

A sharp attenuation characteristic for high frequencies is necessary to remove possible ringing at the accelerometer resonance frequency. In addition, phase distortion must be kept to a minimum in the pass-band, and the step function response

V. (Continued)

should be well-damped. A third-order Butterworth filter offers about the best solution to all three requirements. Such a filter is incorporated in the Model 11 Charge Amplifier.

The attenuation of the third order Butterworth filter[4] is 3 dB at the cutoff frequency to and is 18 dB/octave thereafter. The response of the exact Butterworth filter is -1% at 1/2 f_o. The phase response is given by

$$\theta = -2.075 \frac{f}{f_o} \pm .016 \qquad f < \frac{1}{2} f_o \tag{14}$$

The time delay for a given frequency is $t_d = \theta/2\pi f$. Thus the average time delay for the exact third-order Butterworth filter is:

$$t_d = .330/f_o \qquad f \leq \frac{1}{2} f_o \tag{15}$$

and the peak to peak variation for the same frequency range is

$$\Delta t_d \cong .014/f_o \tag{16}$$

or about $\pm$ 2% variation.

The step function response for the filter is shown in Fig. 6. The response time to 1/2 the final value is the average time delay given in Eq. (15). The overshoot is 9% and the response is within 10% of the final value at $tf_o = .5$ and within 1% of the final value at $tf_o = 1.2$.

Guaranteed amplitude response for the Model 11 is $\pm$ 2% at 1/2 f_o. Two switchable cutoff frequencies are supplied. The actual phase response is within $\pm 2^\circ$ of the best straight line for the phase curve. The positive deviation usually occurs near 1/4 f_o and the negative deviation at 1/2 f_o. This corresponds to about $\pm$ 5% variation of time delay about the average value for frequencies less than 1/2 f_o.

---

[4] Kuo, Network Analysis and Synthesis, pp 329, 332, 347, 349 John Wiley and Sons, 1962.

V. (Continued)

Table 3 gives typical high frequency performance parameters for the Model 11.

Cutoff Freq. f_o	± 2% Amp. Resp.	Attn. at Accel. Resonance 30 kHz	Av. Time Delay td	Time Delay Var. Δtd	Rise Time 90% Final Val.	Settling Time 99 - 101% Final Val.
20 kHz	10 kHz	11 dB	16 μs.	1.5 μs.	25 μs.	60 μs.

Table 3

Typical Characteristics Model 11 Charge Amplifier

Short-duration pulses are rarely rectangular and response errors for triangular, half-sine, and continuous-function pulses are much less than those described for step function responses (rectangular pulses).

Figure 7 shows the response of the filter to a triangular pulse for which $f_oT = 4$. As expected a time delay of about $f_o t_d = .33$ appears. Rounding at the discontinuities in slope occur. The error at the peak is about 4%. The per cent error at the peak response for other pulse durations is approximately

$$\text{percent } \epsilon = \frac{16}{f_o T} \qquad (f_o T > 2) \qquad (17)$$

The response error at the peak of a half-sine pulse is considerably less than that for a triangular pulse of equal duration.

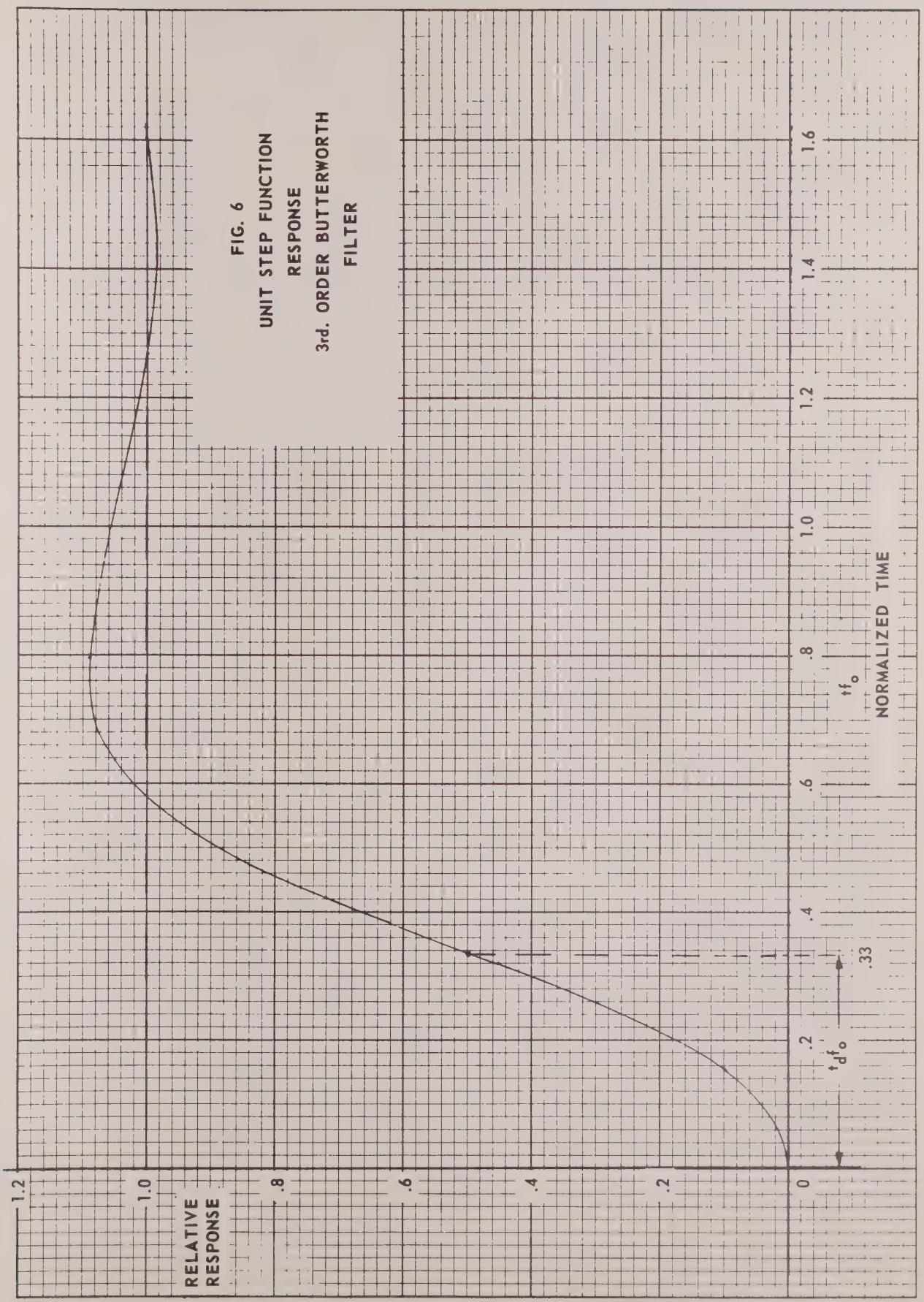
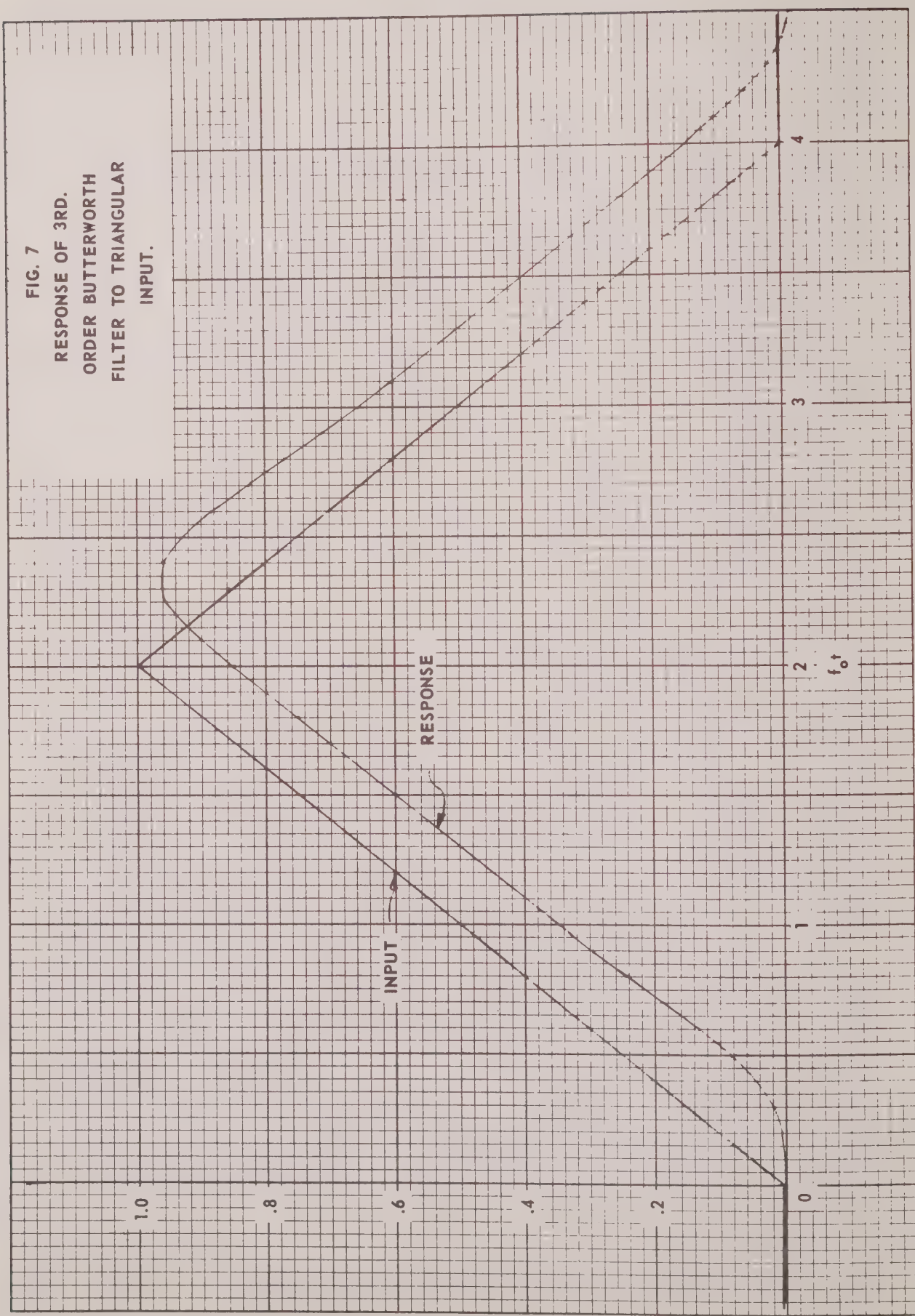


FIG. 6
UNIT STEP FUNCTION
RESPONSE
3rd. ORDER BUTTERWORTH
FILTER
RELATIVE RESPONSE
1.2
1.0
.8
.6
.4
.2
0
.2
.33
.4
.6
.8
1.0
1.2
1.4
1.6
$t_d f_o$
$t f_o$
NORMALIZED TIME



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APPENDIX II

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From the manufacturer of complete vibration test systems

UNHOLTZ-DICKIE

Instrument Bulletin

Offering a complete line of signal conditioning instruments and accelerometers for vibration

ORIGINATORS OF THE CALIBRATED SENSITIVITY DIAL ■ AUTORANGING ■ RANGE RESTORING ■ AUTOMATIC CALIBRATION PLOTTING SYSTEMS ■ HIGH POWER TRANSISTOR AMPLIFIERS

SHOCK AND VIBRATION MONITORING INSTRUMENTS

Unholtz-Dickie instruments can be categorized as two types

COMPACT SIGNAL CONDITIONING MODULES FOR MULTI-CHANNEL DATA ACQUISITION SYSTEMS

These units are generally charge type amplifiers with switchable voltage modes of operation. Their modular construction permits the building block approach and the combination of various features. They have full scale range switching, a direct reading sensitivity dial, variable gain tape output, and optional galvo output, 10mV/g servo output, and meter. Built-in CAL and TEST functions are standard. Other features include AUTO RANGING, LOG COMPRESSION, extended low frequency response, and compatibility with grounded accelerometers. Wide dynamic range and frequency response are particularly suitable for shock measurements.

INSTRUMENTS FOR LABORATORY USE

These units are generally voltage type amplifiers with normalized 10 mV pk/g pk outputs. They are general purpose rack mounted instruments. All have the DIAL a calibrated sensitivity dial for direct dialing user sensitivity. Some models read out velocity in addition to the standard acceleration recording of both acceleration and displacement. High accuracy, precision, standardizer calibrators are used in accelerometer calibration combine switchable charge and voltage inputs integration feature.

GENERALIZED INPUT

TYPE INPUT	INPUT CABLES GENERALLY USED	TYPICAL NOISE LEVELS (referred to input)	TYPICAL [illegible]	COMMENTS
High Input Impedance, Straight Voltage: DAG Series, 608 Series (Voltage mode)	50 ft or less of subminiature, low noise cable.	DAG Series: <100 μV rms 608 Series: <35 μV rms	DAG Series: [illegible] 608 Series: 0 to 5,000	Compatible with wide variety of transducers. Calibration depends on input cable length.
Charge Converter: Model 11 Series, 608 Series	Up to 300 ft of coaxial cable. Connection to accelerometer is subminiature, low noise cable with optional conversion to RG/U coaxial cable runs.	Model 11 Series: .003 pC rms + .002 pC rms/1000 pF 608 Series: .03 pC rms + .01 pC rms/1000 pF	0 to 5,000 mV/pC 608 Series: [illegible]	Calibration is independent of cable lengths normally used. Model 11 series achieves ultra low noise levels for short input cables. Low noise cable required when cable whip is expected.
Remote Impedance Converter: Model 11PA-2 with Model 11 Series (Voltage Mode)	Short length of subminiature, low noise cable connected to accelerometer, and up to 2000 ft of RG/U coaxial cable to rack mounted instrument.	<35 μV rms	unity	Low output impedance drives long cables and uses standard RG/U coaxial types. Compatible with wide variety of transducers. Calibration depends on input cable length.
High Input Impedance, Driven Shield Voltage: 610 Series	25 to 100 ft of special triaxial cable with short length of subminiature low noise cable connected to the accelerometer.	<100 μV rms	0 to 7,000	Reduces capacitance loading effects on accelerometer. Calibration depends on input cable length.

		MODEL	19" Wide Rack Mount	Channels in 19" Width	Portable	Voltage Input (High Impedance)	Charge Input	Voltage Input with Remote Model 11PA-2	1V rms/g peak Normalized Output	10 mV/g Normalized Output	96.4 mV/in/sec Velocity and 1V rms/in DA Disp. Outputs	Adjustable Full Scale Tape Output	Adjustable Full Scale Galvo Output	
DIAL-A-GAIN SERIES		601		1	✓	✓			✓	✓				pg. 6
		601R-A	✓	1		✓			✓	✓				pg. 6
		602		2	✓	✓			✓	optional				pg. 6
		602R	✓	2		✓			✓	✓				pg. 6
		603R	✓	4		✓			✓	✓				pg. 6
		606M		1	✓	✓			✓	optional				pg. 6
		606RM	✓	1		✓			✓	optional				pg. 6
		610RM	✓	1		✓			✓	optional	✓			pg. 6
		610RMG-3	✓	3		driven shield			✓	✓	✓	0-5 V pk	0-10 V pk	pg. 6
		V608R-12A	✓	1		✓			✓	✓	✓			pg. 6
		CV608R-12A	✓	1		✓	✓		✓	✓	✓			pg. 6
608 SERIES		8PMCVA	with 608R	1-6	with 608PS-1	✓	✓			✓		0-2.5Vpk	0-10 V pk	pg. 5
		8PMCV	with 608R	1-6	with 608PS-1	✓	✓			✓		0-2.5Vpk	0-10 V pk	pg. 5
		8PCV	with 608R	1-6	with 608PS-1	✓	✓			✓		0-2.5Vpk	0-10 V pk	pg. 5
		8PMXCV	with 608R	1-6	with 608PS-1	✓	✓			✓		0-2.5Vpk	0-10 V pk	pg. 5
		8PXCV	with 608R	1-6	with 608PS-1	✓	✓			✓		0-2.5Vpk	0-10 V pk	pg. 5
MODEL 11 SERIES	BASIC	D11V	with 11R	1-6	✓		✓	✓		optional		0-5 V pk		pg. 4
		D11MV	with 11R	1-6	✓		✓	✓		optional		0-5 V pk		pg. 4
		D11GV	with 11R	1-6	✓		✓	✓		optional		0-5 V pk	0-5 V pk	pg. 4
		D11MGV	with 11R	1-6	✓		✓	✓		optional		0-5 V pk	0-5 V pk	pg. 4
	AUTORANGER	11MAV	with 11R	1-6	✓		✓	✓		optional		0-5 V pk		pg. 4
		11GAV	with 11R	1-6	✓		✓	✓		optional		0-5 V pk	0-5 V pk	pg. 4
		11MGAV	with 11R	1-6	✓		✓	✓		optional		0-5 V pk	0-5 V pk	pg. 4
	LOG AMP	11MSLV	with 11R	1-6	✓		✓	✓		optional		0-5 V pk		pg. 4
		11GSLV	with 11R	1-6	✓		✓	✓		optional		0-5 V pk	0-5 V pk	pg. 4
		11MGSLV	with 11R	1-6	✓		✓	✓		optional		0-5 V pk	0-5 V pk	pg. 4
	w/11PA-2	V11MS	with 11R	1-6	✓			✓		✓		0-5 V pk		pg. 5
		V11GS	with 11R	1-6	✓			✓		✓		0-5 V pk	0-5 V pk	pg. 5
		V11MGS	with 11R	1-6	✓			✓		✓		0-5 V pk	0-5 V pk	pg. 5

CHARGE/VOLTAGE AMPLIFIERS FOR

conditions signals from piezoelectric tran

MODEL 11 SERIES CHARGE AND VOLTAGE WITH INDIVIDUAL POWER SUPPLIES

This new series of signal conditioning amplifiers features individual double shiel... ...yl-clad, totally enclosed case, solid state printed circuitry, ultra low noise levels, portability of separate units, wider freque... ...able charge or voltage operation. Panel height only 5¼ inches with meters. Full scale ranges of .1 g to 10K g with acc... ...l pC/g to 100 pC/g.

D11 SERIES

Model D11V	Model D11MV	Model D11GV	Model D1...
Tape output only	Tape and meter	Tape and galvo	Tape...
$525.00	$575.00	$590.00	$64...0

... D11 series permits operation with ...ounded accelerometers while eliminating ...al ground loop problems. Differential cir... ...try provides rejection of common mode ...nals by a factor of 1000 or more.

OPTIONAL FEATURES

	10mV/g Servo Output	$50.00
	1 kHz Internal Calibration Oscillator — fixed amplitude, sine wave	$50.00
	Floating DC output for amplifiers supplied with meters	$25.00
R	Large Meter (2½ inch scale) with 8¾ panel height	$20.00
F1	Extended low frequency response (±5% down to 0.2 Hz)	$50.00

AUTORANGER SERIES

Model 811M	Model 11 MAV	Model 11 GAV	Model 11 MGAV
Range restorer	Tape and meter	Tape and galvo	Tape, galvo, meter
$1200.00	$745.00	$760.00	$810.00

...RANGER series selects best of 3 adjacent scale ranges. Pilot light and dc code sig... ...ndicate range selected. Range sequences ...1, 3, 10 . . ., or 1, $\sqrt{10}$, 10 . . . or 1, ...100 . . . are offered. Companion RANGE-...STORER converts tape recorded data to orig... ...inal dynamic range.

OPTIONAL FEATURES

...	...0mV/g Servo Output	$50.00
...	1 kHz Internal Calibration Oscillator — ...fixed amplitude, sine wave	$50.00
	Floating DC output for amplifiers supplied with meters	$25.00
—8	Large Meter (2½ inch scale) with 8¾ panel height	$20.00

LOG AMP SERIES

Model DADC-5	Model 11 MSLV	Model 11 GSLV	Model 11MGSLV
Differential AC-DC converter	Tape and meter	Tape and galvo	Tape, galvo, meter
$1400.00	$800.00	$815.00	$865.00

Log amp series compresses 1000:1 input signal variation to 4:1 output signal variation. Waveform and frequency content of output is same as input. When combined with companion DADC-5, direct measurement of transmissibility can be made down to 5 Hz.

OPTIONAL FEATURES

T	Matched performance and use with Tracking Filter	$200.00
0	1 kHz Internal Calibration Oscillator — fixed amplitude, sine wave	$50.00
F	Floating DC output for amplifiers supplied with meters	$25.00
—8	Large Meter (2½ inch scale) with 8¾ panel height	$20.00

MODEL 11P-2
Dual Channel Portable Adapter
with 2 channels of Model 11 series
Model 11P-2 $70.00

MODEL 11 SERIES
With -8 option

MODEL 11R
Rack Frame Adapter
with 6 channels of Model 11MGA
Model 11R $200.00
Blank Panel $7.50

ucers for driving tape and galvo recorders

ECONOMY MODEL V11 AMPLIFIERS FOR USE WITH REMOTE CHARGE OR VOLTAGE PREAMPLIFIER

The Model V11 amplifier is a lower cost instrument that deletes the charge input stage of the standard Model 11 series and uses a remote preamplifier for conversion of the transducer output to a low impedance signal. The remote preamplifier can be selected as either the Model 11CA-2 charge input type or the Model 11PA-2 voltage input type. The Model V11 amplifier has screw driver adjustment for the tape and galvo outputs, a 2 position calibrate switch, Option I full scale ranging, and deletes the switchable filter feature. **V11MS $445.00**
V11GS $465.00
V11MGS $510.00

MODEL 11CA-2 REMOTE CHARGE PREAMP

When connected to any Series 11 amplifier, this low noise remote charge preamplifier eliminates cable noise and provides a 1 mV/pC conversion gain. The less than 50 ohm output impedance drives up to 2000 feet of standard RG/U coaxial cable. The unit is packaged as a BNC to Microdot type adapter. **$80.00**

MODEL 11PA-2 REMOTE VOLTAGE PREAMP

When connected to any Series 11 amplifier, this remote voltage preamplifier provides 1000 megohm input impedance, less than 50 ohm output impedance, and unity gain. This preamplifier is particularly suitable for use with "voltage" type piezoelectric transducers and is compatible with both resistive and capacitive type transducers. The low output impedance eliminates cable noise problems and will drive up to 2,000 feet of standard RG/U coaxial cable. The unit is packaged as a BNC to Microdot type adapter. **$50.00**

MECHANICAL IMPEDANCE & TRANSMISSIBILITY ACCESSORIES

These basic building block components permit automatic plotting of mechanical impedance, transmissibility, or the ratio of two complex quantities. The frequency range of 5 Hz to 20 KHz is covered with a dynamic range capability of up to 120dB. Each instrument contains its own power supply and can be used as a separate, portable unit when not mounted in the Model 11R Rack Frame Adapter.

MODEL 11MGSL	MODEL 11MGSL	MODEL DADC-5	MODEL LFC-5	MODEL MAC-2	MODEL MC-10

Model 11MGSL
Any of the log type charge amplifiers, with the options described on page 4, eliminate the need for 2 separate log converters and fulfill a wide range of signal conditioning requirements.

Model DADC-5
Differential AC-DC Converter. DC output represents ratio of the two measured quantities. $1,400.00

Model LFC-5
Log Frequency Converter. DC output represents logarithm of input frequency. $750.00

Model MAC-2
Averaging Control. Permits control to weighted average of measured quantities. $650.00

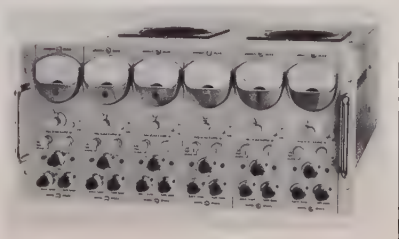
Model MC-10
Mass Compensator. Compensates for component of measured force used to drive head of force transducer. $495.00

608 SERIES CHARGE AND VOLTAGE WITH COMMON POWER SUPPLY

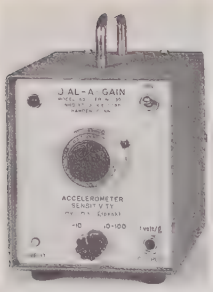
8PMCVA Auto-Ranger	8PMCV	8PCV	8PMXCV	8PXCV
Automatic Ranging				
Meter	Meter		Meter	
Galvo output	Galvo output	Galvo output		
Tape and servo output	Tape and servo output	Tape and servo output	Tape and servo output	Tape and servo output
$655.00	$485.00	$425.00	$415.00	$355.00

608PS-1 PORTABLE POWER SUPPLY WITH PLUG-IN MODULES Accepts up to two modules in any combination
608PS-1 $410.00

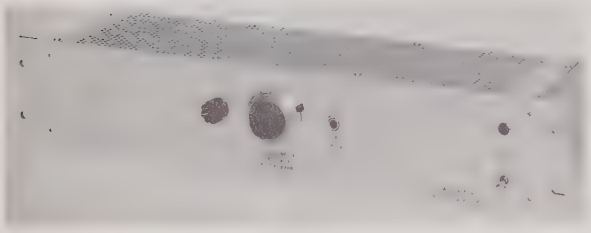
608R POWER SUPPLY AND RACK FRAME ADAPTER WITH PLUG-IN MODULES Accepts up to 6 modules in any combination
608R $540.00



DIAL-A-GAIN SERIES VOLTAGE AMPLIFIERS

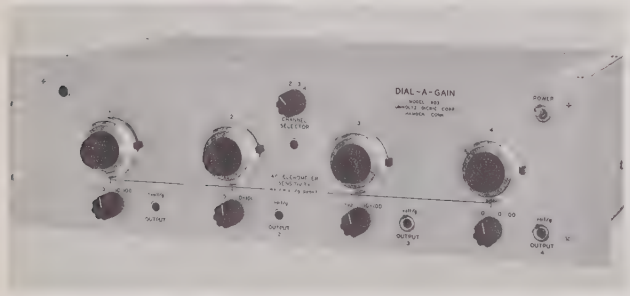


MODEL 601 **$225.00**
General purpose portable instrument for measurement of acceleration. Convenient 1 V rms/g pk and 10 mV/g outputs for readout on oscilloscope or voltmeter. .01 g to 100 g without range switching. Direct dialing of any accelerometer sensitivity from 1 to 100 mV rms/g pk

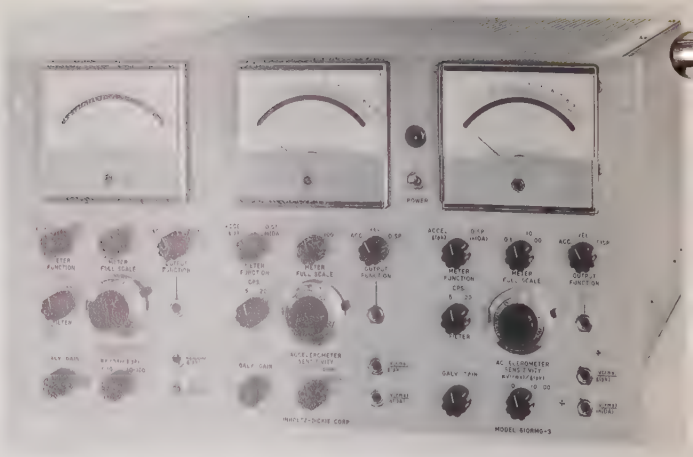


MODEL 601R-A **$260.00**
Rack mounted version particularly suited for exciter system servo control. Operation with the Model 20D21 accelerometer provides excellent low level displacement control down to 5 Hz.

MODEL 602 **$375.00**
MODEL 602R (rack mount) **$410.00**
2 channel version. Front panel switch selects either channel for easy monitoring or comparison on external voltmeter



MODEL 603R **$695.00**
Low cost 4-channel instrument



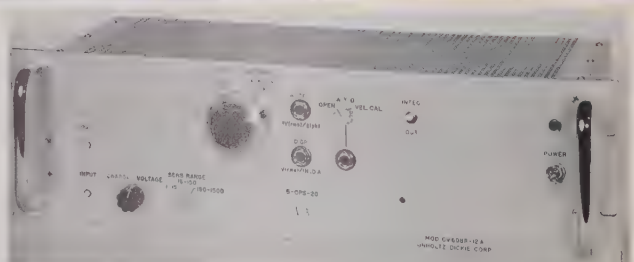
MODEL 610RMG-3 **$2,150.00**
This versatile vibration monitoring instrument combines double integrating features with high current outputs for driving high frequency galvanometers. Acceleration outputs normalized at 1 V rms/g pk and 10 mV/g in addition to full scale ranging at 1, 10, 100 g. Velocity output at 96.3 mV/in/sec. Displacement output normalized at 1 V/in DA and full scale ranged at .1, 1, 10 in. DA. Galvo output adjustable from 0 to 10 V pk full scale level. Large, accurate logarithmic meters indicate acceleration or displacement. Driven shield input with 25′ triaxial cable supplied for each of the three channels.

MODEL 610RM **$730.00**
Single channel, rack mounted, double integrating, no galvo output

MODEL 606M **$395.00**
MODEL 606RM (rack mount) **$430.00**
Same as Model 601 with integral meter and full scale ranges of 1, 3, 10, 30 and 100 g

MODEL V608R-12A **$975.00**

Reference accelerometer is connected to one V or CV standardizer and unknown accelerometer is connected to a second V or CV standardizer. When outputs are adjusted equal, the sensitivity of the unknown accelerometer is read directly on the precision sensitivity dial of the unknown channel. This procedure is applicable to accelerometers, velocity pickups, or other transducers, since these double integrating instruments have acceleration, velocity, and displacement outputs. Acceleration frequency response is within ±0.5% from 10 Hz to 10 KHz (since both channels are matched this error virtually disappears). Velocity response is ±1%, 10 Hz to 2 KHz. Displacement response is ±1.5%, 10 Hz to 70 Hz.



MODEL CV608R-12A **$1,500.00**

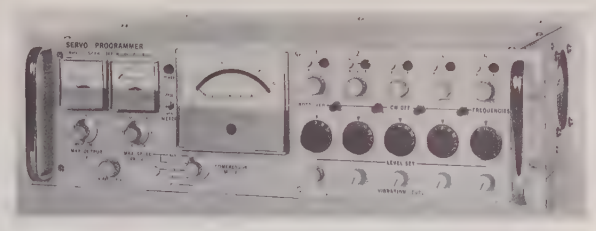
ACCESSORY INSTRUMENTS
for control and protective functions

MODEL AFP SERIES
ARBITRARY FUNCTION PROGRAMMER

- Curve follower programs arbitrary function of acceleration vs. frequency
- 50 dB amplitude range
- 3 decade frequency range
- Controls average or largest of several accelerations to program
- Use with MAC-6C or ATC-6

Model AFP-1 **$3,475.00**
(Use with SP-1M, SP-2 and SP-5 servo and MAC-6C)

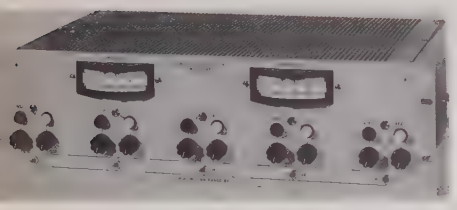
Model AFP-6 **$4,950.00**
(Use with ATC-6 and BK 1025)



SERVO PROGRAMMERS

Features: Combines functions of amplitude servo and vibration programmer in one instrument ■ Programmer contains up to five program segments with servo controlled acceleration, velocity, or displacement selectable for each segment (SP5) ■ Simplified closed-loop presetting of vibration levels before actual test is performed ■ Solid state, plug-in, printed circuit construction ■ Analog output for recording levels.

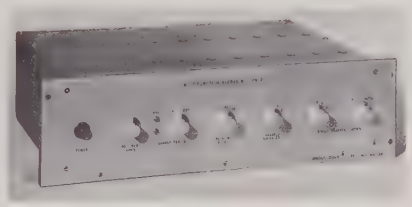
MODEL SP-5 (5 segment programmer) **$4,330.00**
MODEL SP-2 (2 segment programmer) **$2,330.00**
MODEL SP-1M (servo only, vibration meter) **$1,750.00**



MODEL AP-5
AUTOMATIC PROGRAMMER
FOR BK SERVOS

- Up to five programmed vibration levels
- Any combination of displacement and acceleration in sequence
- Any combination of velocity and acceleration in sequence
- Amplitude settings with 100 to 1 range
- Direct vibration reading on BK 1039 or BK 1025 at all times
- Complete independence of amplitude and transfer frequency controls
- Pilot lights indicate mode of operation at all times
- Programmed control can be switched out for normal operation
- Size 19" wide x 5¼" high

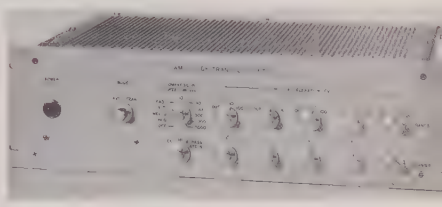
Model AP-5 (including rework of BK) **$2,000.00**



MODEL MAC-6C
MULTIFUNCTION AVERAGING CONTROL

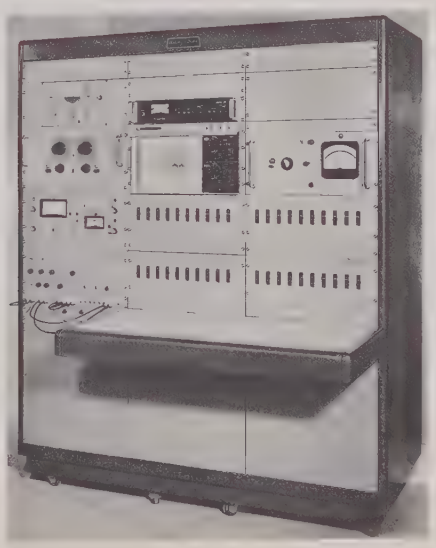
Features: Phase insensitive averaging for at least 6 inputs • Allows averaged shaker system control for sine and random tests • Sine tests: absolute average of output yields average of input magnitudes • Random tests: spectral density of output yields average of input spectral densities • Freedom from detector time constant problems. • 2 or more units can be coupled • Analog DC output
Model MAC-6C **$1,850.00**

Model MAC-2. Two channel unit in model 11 modular case. Increases dynamic range of impedance system by controlling to weighted average of force and acceleration.
Model MAC-2 **$650.00**



MODEL ATC-6
AMPLITUDE TRANSFER
OR AVERAGE CONTROL

Features: Dual function instrument provides control of sine tests from highest of up to six acceleration inputs or from their average • Transfer mode maintains acceleration of each input at or below individually pre-set levels • Negligible overshoot when control transfers from one channel to another • Average mode provides control from phase-insensitive average of input accelerations • 2 or more units can be coupled • Operates with BK 1039 and BK 1025 only
Model ATC-6 **$2,400.00**



RV500B RANDOM NARROW BAND
EQUALIZER AND RECORDING
ANALYZER

Complete Random Control Center for use with any sine shaker system. Equalizer section includes noise generator, spectrum shaping filter, shaker equalizer, forty channel specimen equalizer, adjustable acceleration level clipper and provisions for mixing sine and random. Analyzer section includes true rms voltmeter, sweeping narrow band analyzer with switchable filters, and log converter and plotter for recording spectral density vs frequency. Analyzer may also be used as random reject filter for conducting servo controlled combined sine-random tests. Patch panel allows use of analyzer as a tracking filter during sine tests.

MODEL E105
SPECTRUM SHAPER

- Simple economical method of converting sine shaker systems for random testing with small specimens
- Fourteen band-pass filters covering the frequency range from 20 cps to 2KC with independent amplitude control allows flattening the shaker-specimen frequency response
- Typical systems with light specimens can be adjusted within ±1½ db of a flat response
- Also includes provisions for shaping the spectrum (other than flat) as required by some specs
- Provisions for mixing sine and random signals

Model E105 (14 channels) **$1,750.00**

ACCELEROMETERS

MODEL		VOLTAGE SENS. mV pk/g pk	CHARGE SENS. pk PCMB/g pk	CAPACITANCE PF	MOUNTED RESONANT FREQ.	SIZE WEIGHT in - grams	DESIGN TYPE	CRYSTAL MATERIAL	PRICE
*2E3 *2E5	Subminiature, extremely small, lightweight for highest frequencies or minimum added mass. 2E5 has wrenching flats for removal.	2.5	1.0	380	70 KHz	.225 Dia. x .225 Ht. .065 grams	Shear Integral Cable Adhesive Mount	PZT.	$213.00
*5D21-8	General purpose. Relatively small with moderately high resonance. Recommended for charge use.	4.0	8.0	2000	40 KHz	.50 Hex. x .64 Ht. 13 grams	Shear Top Connector 10-32 Mtg. hole	PZT.	$185.00
*5D21	Similar to 5D21-8. Recommended for voltage use.	6.5	12.0	2000	40 KHz				
*10D21	Similar to 5D21 with slightly increased sensitivity. Recommended for voltage use.	9	13.0	1400	35 KHz				
*10DQ21	General purpose with side connecting cable for restricted height applications.	20	40	2000	30 KHz	.62 Hex. x .71 Ht. 25 grams	Shear Side Connector 10-32 Mtg. hole	PZT.	$185.00
*5D41	High internal capacitance for direct connection to a scope or VTVM.	7.5	75	10000	30 KHz	.62 Hex. x .71 Ht. 25 grams	Shear Top Connector 10-32 Mtg. hole	PZT.	$213.00
*20D21	General purpose. Recommended for voltage use when 35 foot or longer accelerometer low noise cable is used.	20	30	1500	30 KHz				$185.00
*25D21	Similar to 20D21. Recommended for voltage use when 50 foot or longer accelerometer low noise cable is used.	27	38	1400	30 KHz				
*13D6B	Approximately flat voltage and charge sensitivity vs frequency from 5 Hz to 5 KHz	13	5	375	30 KHz				$200.00
*75D21	Maximum voltage and charge sensitivity gives best signal/noise ratios for very low level vibration measurements.	70	70	1000	20 KHz	.75 Hex. x .70 Ht. 37 grams			$185.00
8B6	Wide temperature range —300° to +500° F. Approximately flat voltage and charge sensitivity vs frequency from 5 Hz to 5 KHz.	3.3	8.0	2400	30 KHz	.76 Dia. x .88 Ht. 36 grams	Compression Double Base Top Connector 10-32 Mtg. hole	Bismuth Strontium Titanate	$220.00
8Q10	Quartz precise calibration standard. Designed to be used as NBS Calibrated Standard. Minimum variation in sensitivity with temperature, approximately flat voltage and charge sensitivity vs frequency.	9.0	2.0	225	30 KHz			Quartz	$310.00

*Shear type piezoelectric construction for least base or case strain and cable motion response to external inputs.

Request quantity discount schedule

Some instruments available for 220 volt, 50 cycle, packed for export at 7.5% extra; check with factory.

Specifications and prices subject to change without notice.

manufacturers of shaker systems, advanced instrumentation, and accelerometers

UNHOLTZ-DICKIE CORPORATION

3000 WHITNEY AVE. / HAMDEN, CONN. 06518 / (203) 288-3358

UNHOLTZ-DICKIE CORPORATION

vibration generation systems and measurement instruments

ACCELEROMETER AMPLIFIER-STANDARDIZER

MODEL 601R-A DIAL-A-GAIN

FEATURES

- o Ten turn, calibrated input sensitivity dial
- o Single valued input sensitivity ranges 1-10 and 10-100 mv/g
- o Standardized outputs - 10 mv/g and 1 volt/g
- o 80 dB signal to noise ratio - 100 g full scale, 0.01 g noise level without range switching
- o Low hum and noise levels - output can be double integrated for displacement servo-control
- o Frequency range 5 Hz to 10 kHz

This instrument is designed to convert the high source impedance voltage from a piezo-electric accelerometer or transducer to a low impedance, standardized voltage. Setting the input sensitivity dial to the sensitivity of the connected accelerometer and cable (mv/g), automatically adjusts the gain of the instrument so that the calibrated outputs are 10 mv/g and 1 volt/g. The 10 mv pk/g pk signal is normally used to establish the feedback acceleration signal required by the automatic shaker amplitude servo control. The 1 volt rms/g pk signal is used for monitoring the instantaneous acceleration signal and its magnitude can be measured by a VTVM. The measured rms volts corresponds to acceleration pk without a scale factor.

The 601R-A is particularly convenient in a vibration test when changing from one accelerometer to another accelerometer located at a point of interest on the test item or fixture. If, for example, the first accelerometer is the calibrated internal unit in the shaker table and the second accelerometer and cable with known calibration is desired for control of the test, the second accelerometer can be connected in place of the first and the vibration test system is recalibrated by simply setting the sensitivity (mv/g) of the second accelerometer and cable on the sensitivity dial. If the calibration of the second accelerometer is not known, it can be determined by making the indicated "g" level the same as that indicated by the internal reference accelerometer at a low frequency where all points have the same motion. The reading on the sensitivity dial then becomes the calibration of the accelerometer.

The 601R-A includes a cathode follower input, a variable gain amplifier and a cathode follower output. Voltage regulation is included in the B+ supply.

SPECIFICATIONS

INPUT IMPEDANCE:
300 megohms minimum

INPUT VOLTAGES:
8 volts rms (sine) maximum

OUTPUT:
(a) 1 volt rms/g pk - 100 volts rms (sine) max. into 200 k ohm or more
(b) 10 mv pk/g pk - 1.0 volt pk max. into 25 k ohm or more

FREQUENCY RESPONSE:
±2% 5 to 5000 Hz. At 10 kHz less than 3% down from 5 kHz with accelerometer sensitivities of 5 to 10 mv/g and less than 80 g equivalent output level.

SENSITIVITY DIAL:
10 turn, lockable, with 3 digit numerical graduations.

SENSITIVITY RANGE:
Input sensitivity from 1 mv rms/g pk to 100 mv rms/g pk in two switchable ranges of 1-10 and 10-100.

SENSITIVITY DIAL LINEARITY:
At any fixed frequency and any dial setting from 2.00 to 10.0 and with a constant input voltage, the output voltage vs the dial setting will be within ± 1.5% of the best straight line approximation.

OVERALL GAIN ACCURACY:
With the sensitivity dial set at 10, range set at 1-10, the output/input voltage gain accuracy will be within 1% at midband frequencies.

VOLTAGE GAIN:
Continuously variable from 10 to 1000:1 with precision sensitivity dial potentiometer and 2 range decade switch.

HUM AND NOISE:
With typical 10 mv rms/g pk accelerometer connected to the input, the output hum and noise as read on a typical VTVM is less than .010 g rms.

FRONT PANEL:
Size - 3½ x 19 inches (5½ deep less cables)
Power on-off switch with pilot
Sensitivity dial
Range switch 1-10; 10-100
Output phone jack - 1 volt rms/g pk

REAR CONNECTIONS:
Input power cord attached (105-125 volts, 60 Hz, 25 VA)
Accelerometer input - female miniature coax (microdot 31-50)
1 volt rms/g pk output - BNC
10 mv pk/g pk output - BNC

UNHOLTZ-DICKIE CORPORATION
2994 Whitney Avenue, Hamden, Connecticut,
Area Code 203 288-3358

PIEZOELECTRIC ACCELEROMETER
GENERAL PURPOSE MODEL 20D21

The Model 20D21 combines a good voltage output with a wide frequency range in a medium size case. The crystal is used in the shear-mode design, well known to be superior for case and base insensitivity. The shear-mode design also affords the best cross axis sensitivity of any type.

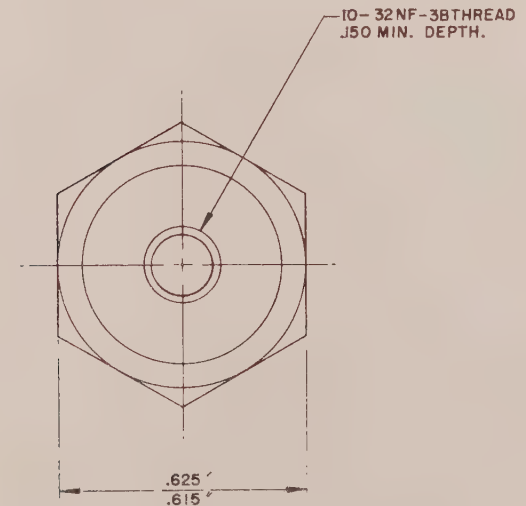
MODEL 20D21

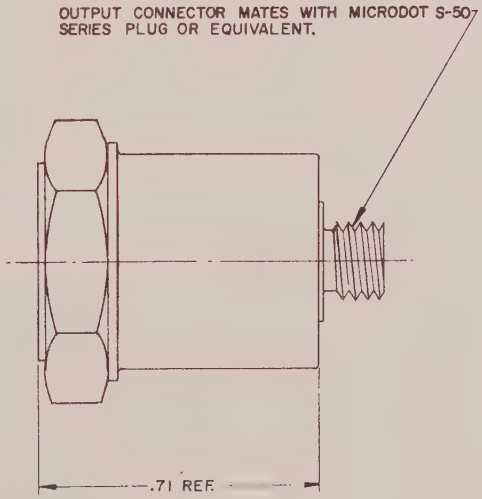
APPLICATION

This accelerometer is similar to the 25D21, but has a voltage sensitivity which has been designed for better match with the sensitivity setting on voltage type amplifiers in shaker systems with typical cable lengths approximately 35 ft. long.

MAIN FEATURES

Voltage Sensitivity: 21 mV pk/g pk, open circuit
Accelerometer Capacitance: 1500 pF
Crystal: Shear-type, lead zirconate-titanate
Mounted Resonance Frequency: 30,000 Hz
Low Base Strain and Cross Axis Sensitivity
Case Insensitive: No cable whip or thermal shock problems
Temperature Range: -165°F to +325°F





CALIBRATIONS

Each accelerometer is calibrated for voltage and charge sensitivity versus frequency by the comparison method from an NBS traceable reference accelerometer. Capacitance, resistance, cross axis sensitivity are also measured on each unit. Every unit is checked for case sensitivity.

	Quantity	1 Each	2 – 4	5 – 9	10 – 24	25 Up
PRICES	Price Each	$185.00	$175.00	$160.00	$155.00	$150.00

All prices are FOB Hamden, Connecticut, and subject to change without notice.

PIEZOELECTRIC ACCELEROMETER GENERAL PURPOSE MODEL 20D21
SPECIFICATIONS

Electrical	
Voltage Sensitivity, open circuit - mV pk/g pk	21
Voltage Sensitivity, with recommended load – mV pk/g pk	14
(Recommended external load, capacitance pF)	(750)
Accelerometer Internal Capacitance – pF	1500 pF
Charge Sensitivity – pC pk/g pk	33
Mounted Resonance Freq.– Hz	30,000
Cross Axis Sensitivity, maximum (at 200 Hz)	3%
Accelerometer Resistance Room Temp. – Megohms	20,000
+350°F – Megohms	500
Frequency Response, volt. sens., ±5% var., 400 meg. load	0.7 Hz to 6 kHz
Amplitude Linearity Percent	2%
Range	2000 g

Mechanical		
Design Type – shear type, grounded case		Top Connector
Crystal Material (See note 5)		Clevite PZT®
Size:		.62 Hex .71 Ht.
Weight:	Ounces	0.9 ozs.
	Grams	25 grms.
Mounting		10-32 hole
Case Material		Stainless steel
Environmental		
Dynamic Range, g's:	Vibration	1000 g
	Shock	2000 g
Humidity, Sealing		Hermetic Grade A
Temperature Range for ± 2½% Volt. Sensitivity variation, with recommended ext. capacitance		-75°F to +225°F
Temperature Range for ± 5% Volt. Sensitivity variation, with recommended ext. capacitance		-165°F to +325°F
Base Strain Sensitivity, equivalent g's per 100 microinch strain		1 g maximum

NOTES:

1. Charge sensitivity variation vs. temperature:
   ±10% variation of sensitivity about room temperature value is obtained over temperature range -65°F to +200°F; ±5% variation over temperature range 0°F to 165°F. (Note: No series capacitance compensation included.)
2. Charge sensitivity vs. frequency:
   Approximately 2.4% drop in sensitivity per decade of frequency from .1 Hz up, inherent characteristics of crystal accelerometer material.
3. Capacitance change vs. frequency:
   Approximately 2.4% drop in capacitance per decade of frequency from .1 Hz up, inherent characteristics of crystal accelerometer material.
4. Thermal shock:
   For a 50°F step function in temperature applied to the case of the accelerometer, less than 1 equivalent 'g' output signal obtained, with 2 Hz high pass filter in preamplifier.
5. Crystal Material: Clevite Corp. PZT®, a lead zirconate-titanate ceramic composition with a Curie Point temperature of 365°C.
6. Acoustic Sensitivity less than .1 g rms at 100 dB broadband.
7. Altitude – Not affected.

UNHOLTZ-DICKIE CORPORATION

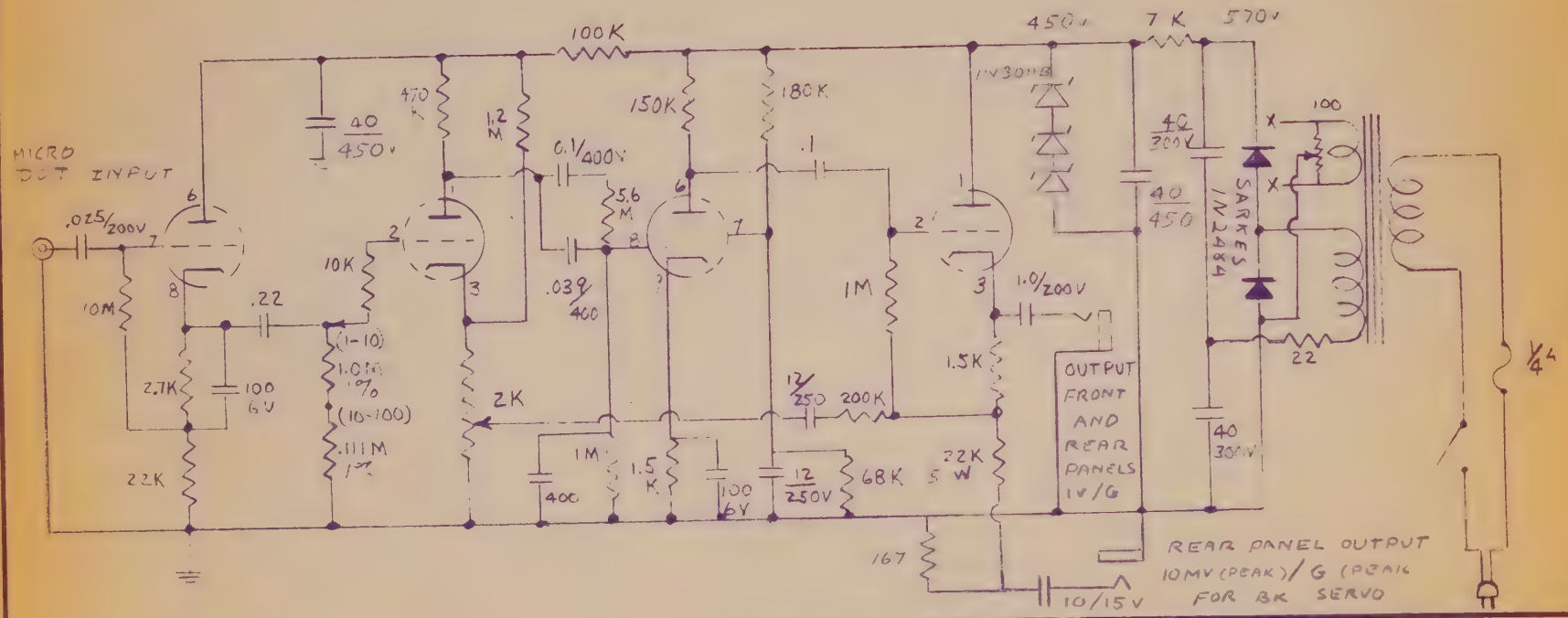
2994 Whitney Avenue, Hamden, Connecticut 06518

Area Code 203 288-3358

2M

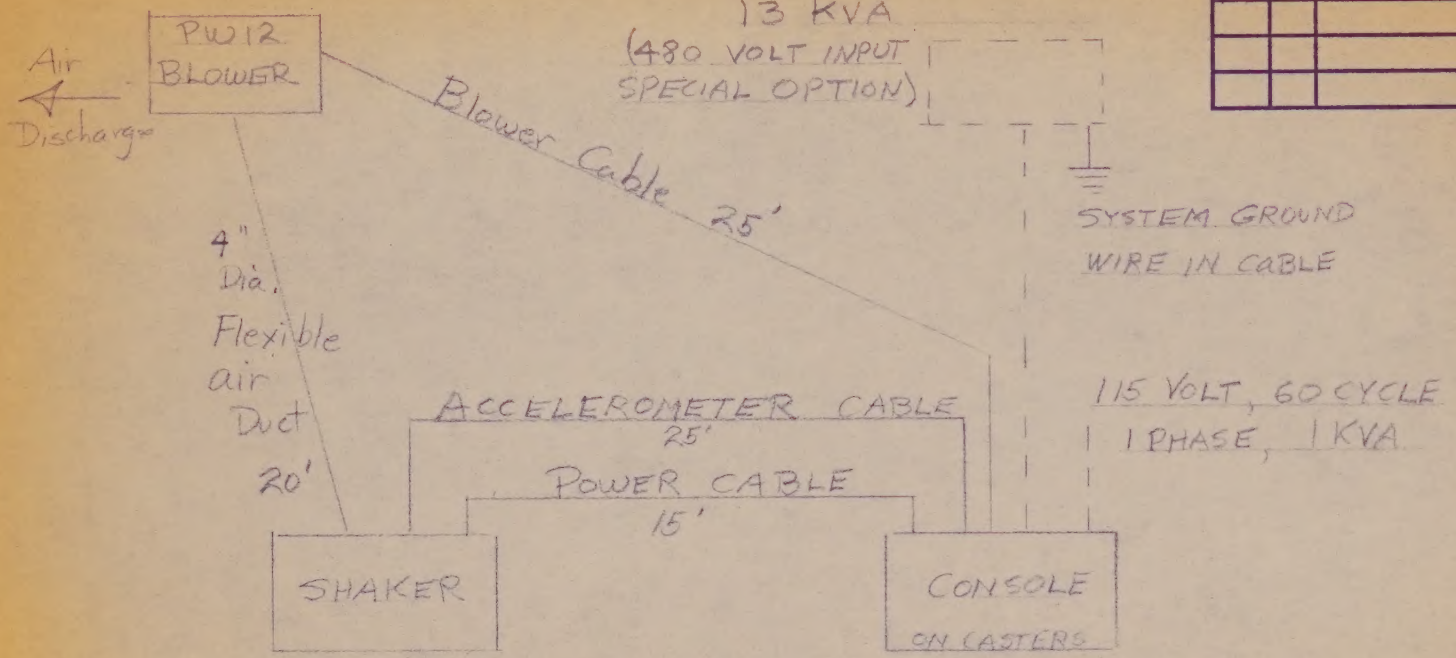
Bulletin 20D21-4-68
Printed in U.S.A.

DATE	SYM	REVISION RECORD	AUTH	DR	CK.



TOLERANCES (EXCEPT AS NOTED)	UNHOLTZ - DICKIE CORP.		
DECIMAL ±		SCALE ~	DRAWN BY APPROVED BY JR
FRACTIONAL ±	TITLE: DIAL-A-GAIN SCHEMATIC MOD 601R-1		
ANGULAR ±	DATE	DRAWING NUMBER: 9104058	

DATE	SYM	REVISION RECORD	AUTH.	DR.	CK.
12-4	A	4" DIA SN 103 UP			
1/28/68	B	add 480 v input option			



- - - - - - Furnished by customer

——— Furnished with system

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FRACTIONAL ±	TITLE: Customer Info., Utilities 262 System		
ANGULAR ±	DATE: May 8 67	DRAWING NUMBER: 910 6899	

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